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# SOUTHERN AFRICA
## A CLIMATOLOGICAL STUDY

by

Maj Kathleen M. Traxler
Capt Richard D. Arnold
John W. Louer III
Michael T. Gilford
MSgt Joy L. Harding
TSgt Richard C. Bonam
Kenneth R. Walters Sr.
Capt Christopher A. Donahue



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APPLICATION CENTER
859 Buchanan Street
Scott Air Force Base, IL 62225-5116

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Terry Laing

TERRY LAING, Lt Col, USAF
Chief of Operations

FOR THE COMMANDER

Carol L. Weaver

CAROL L. WEAVER
Scientific and Technical Information
Program Manager
*31 October 1994*

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13. Abstract: A climatological study of Southern Africa, a region that comprises The Republic of South Africa, Zimbabwe, Namibia, Lesotho, Swaziland, Botswana, Madagascar and the southern parts of Mozambique, Angola, Zaire, and Zambia. After describing the geography and major meteorological features of the entire study area, the study discusses the major climatic controls of each of Southern Africa's six "climatic commonality" regions in detail. Each "season" is defined and discussed in considerable detail, to include typical weather, clouds, visibility, winds, precipitation, and temperature.


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# PREFACE

This study was prepared by the United States Air Force Environmental Technical Applications Center, Readiness Support Branch (USAFETAC/DOJ) in response to a support assistance request from the Air Force Global Weather Central (AFGWC), Offutt AFB, NE, under the provisions of Air Force Instruction 15-118. Publication completes part of USAFETAC project 901033; completion of a similar study for Equatorial Africa will complete the project, which would not have been possible without the dedicated support of the many people and agencies we have listed below. First, our deepest gratitude to the late Walter S. Burgmann, director of the Air Weather Service Technical Library. His guidance will be sorely missed. Thanks to Dr. Carol Weaver for the technical assistance and good advice in making this document easier to read.

We appreciate the expert assistance of Wayne E. McCollom, David P. Pigors, Charles Travers, Gary Swanson, Kay Marshall, Susan Keller, Susan Tarbell, Lisa Mefford, and Randa Simon of the Air Weather Service Technical Library (DOL). Without their assistance, much of the information in this document, obtained from worldwide sources, would simply not have been available.

Thanks to all the people in the USAFETAC Environmental Applications Branch (DOC) who provided the immense amount of data required for the preparation of this regional. The work of Charles Glauber, Michael Squires, Capt Matthew Williams, 1st Lt Michael Protz, TSgt Maria Greenwood, SSgt Sonny Bernal, MSgt Stephen Gross, TSgt William Thompson, and SSgt Andrew Henderson are especially appreciated.

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Finally, the authors owe sincere gratitude to USAFETAC's Technical Publishing Team—George M. Horn, Robert Van Veghel, Rita Markus, and SrA Lela Hartman—for their patience, cooperation, and creativity.

## TABLE OF CONTENTS

## FIGURES

# Chapter 1

## INTRODUCTION

**Area of Interest.** This study describes the geography, climatology, and meteorology of Southern Africa. The area known as "Equatorial Africa" is described in another USAFETAC technical note. Southern Africa has been divided into the six "zones of climatic commonality" shown in Figure 1-1; these zones will be described separately, in turn.

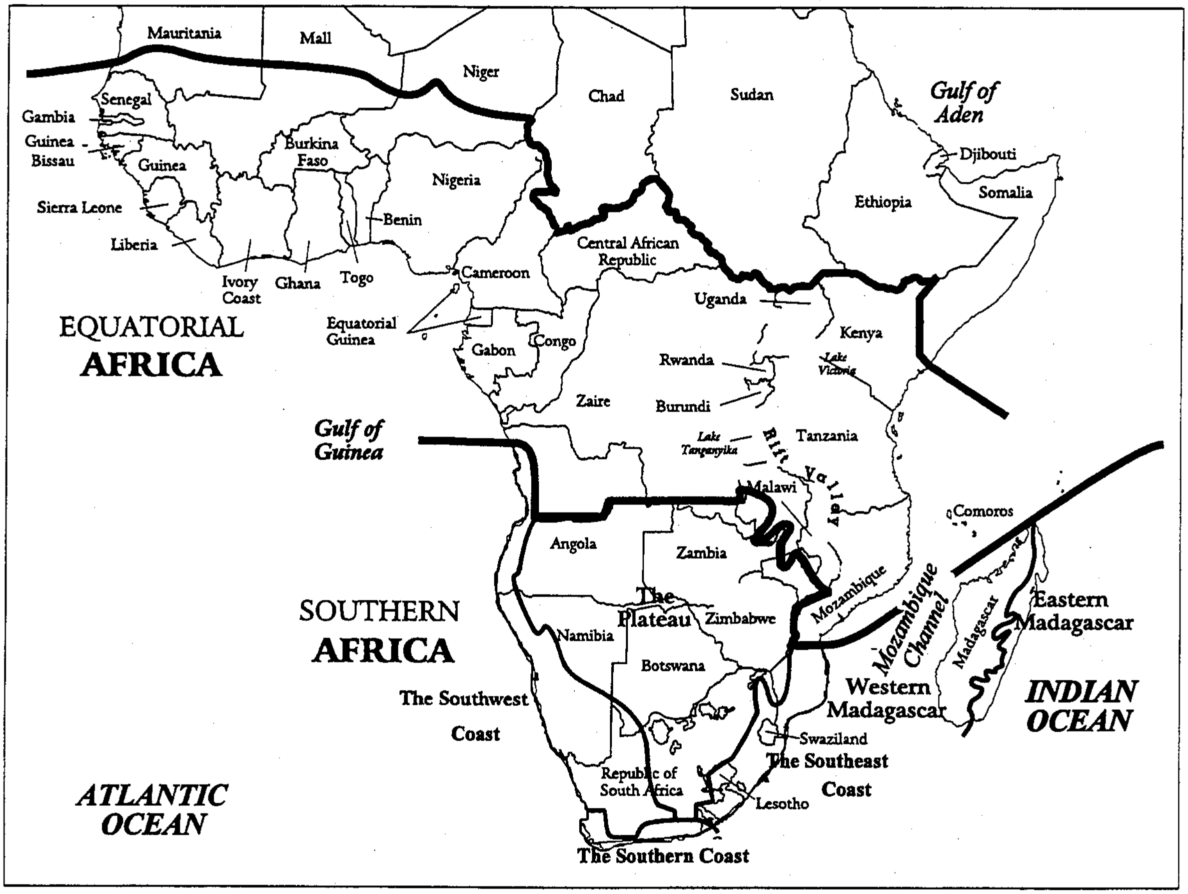



**Figure 1-1. Southern Africa, shown here in relation to Equatorial Africa, a region described in a separate USAFETAC technical note.** For the purposes of this study, Southern Africa has been divided into six "zones of climatic commonality" (the Southern Coast, the Southwest Coast, the Plateau, the Southeast Coast, Western Madagascar, and Eastern Madagascar).

- *The Southern Coast* is the extreme southern tip of South Africa. It is the region's only temperate zone, with four standard seasons. Cold fronts sweep across the area year-round. The northern boundary is the extent to which precipitation amounts drop under 250 mm on the west coast, and where a November-March wet season occurs (rather than the four temperate zone seasons) elsewhere.

- *The Southwest Coast* includes western Angola, Namibia, South Africa, and southeastern Botswana. Dry year-round (less than 250 mm annually), it encompasses not only the southern Atlantic Coast ("Skeleton Coast") but the desert areas of the interior. The little rain that this region receives falls between November and March. The boundaries are the lines at which annual rainfall exceeds 250 mm.

• *The Southeast Coast* includes southern Mozambique, Swaziland, Lesotho, and eastern South Africa. This region receives the Indian Ocean trades and is affected by frontal systems that cause a wet season between October and March and a dry season between April and September. The limit of these seasons determines the southern boundary. The northern boundary is the northern limit of the trades. The western boundary is the ridgeline of the mountain range that rims Africa's plateau.

• *The Plateau* includes southeastern Angola, western Zambia, extreme southern Zaire, west-central Mozambique, Zimbabwe, most of Botswana and the central portion of South Africa. This high interior region is mostly arid or semi-arid. The wet season runs from November to March; the dry season, from May to September. The northern boundary is the edge of the Congo (Zaire) River Basin. The western edge is the peak of the range separating the drier interior from the ocean boundary layer. The eastern boundary is the ridgeline of the mountain range that rims the Plateau and defines the extent of enhanced precipitation and stratus carried inland from the Indian Ocean. The southern boundary is the limit of the wet and dry seasons described above, and where the temperate zone begins.

• *Western Madagascar* includes both the west coast and the mountains that form the island's axis. The warm season is from December to March; the cool season, April through October. The eastern boundary is the 600-meter contour that defines the eastern edge of the central plateau and mountains.

• *Eastern Madagascar* is the island's Indian Ocean coast. It is wet year-round, with a cool season from May through October and a warm season from November through April. The western boundary is the 600-meter contour.

**Study Content.** Chapter 2 provides a general discussion of the major meteorological features that affect Southern Africa. These features include semipermanent climatic controls, synoptic disturbances, and mesoscale and local features. The individual treatments of each region in subsequent chapters do not repeat descriptions of these phenomena; instead, they discuss specific effects of these features unique to that region. Therefore, meteorologists using this study should read and consider the general discussion in chapter 2 before trying to understand or apply the individual climatic zone discussions in chapter 3 through 8. This is particularly important because this study was designed with two purposes in mind: first, as a master reference for Southern Africa; and second, as a modular reference to each individual subregion, or "zone of climatic commonality."

Chapters 3 through 8 amplify the general discussions in Chapter 2 by describing the geography, climate, and meteorology of each subregion. These chapters provide detailed discussions of the regions that are known to feature reasonably homogeneous climatology and meteorology. However, in mountainous areas, weather and climate is not necessarily homogeneous; they can be distinctly different from areas immediately adjacent.

In each region, geography is discussed first (including topography, rivers and drainage systems, lakes and water bodies, and vegetation). Next, major climatic controls, and, if appropriate, special climatic features, are described. Weather for each season is then discussed, organized in the following order:

- General Weather
- Sky Cover
- Visibility
- Winds (including upper winds)
- Precipitation
- Thunderstorms
- Temperature
- Other Hazards

All regions but one (the Southern Coast) have wet and dry or warm and cool seasons instead of the standard temperate winter, spring, summer, and fall. Transitions between these two seasons are, in most cases, too short to warrant separate transition season discussions. The length of each season varies from region to region.

**Conventions.** The spellings of place names and geographical features are generally those used by the United States Defense Mapping Agency's Aerospace Center (DMAAC), with several exceptions. One example is "Cape Town," Republic of South Africa, which is almost always spelled "Capetown" in graphics. Another is the "Republic of South Africa" itself, which is generally referred to in text as "South Africa."

Distances and elevations are in meters below 10 kilometers and in kilometers (km) above. Cloud and celing heights are in feet. When the term "ceiling" is used, it means 4/8 cloud coverage *at any level* unless specified otherwise. Temperatures are in degrees Celsius (° C). Wind speeds are in knots. Precipitation amounts are in millimeters (mm). Most synoptic charts are labeled in Greenwich Mean Time (GMT or Z). When synoptic charts are *not* provided, only local time (L) is used.

Unless otherwise stated, cloud bases are above ground level (AGL); tops are above mean sea level (MSL). Since cloud bases are generalized over large areas, readers must consider terrain in discussions of cloud bases in and around the mountains.

In the figures that give mean monthly rain, snow, and thunderstorm days, "rain days" include those on which WMO present weather codes 21, 23-26, 50 through 69, 80 through 84, 91, 92, 94-97, or 99 are reported. "Snow days" include days on which present weather codes 22, 23, 70 through 75, 77, or 85 through 88 are reported.

"Thunderstorm days" are those on which codes 17 or 91 through 99 are reported. A "fog day" is one on which 40-49 are reported.

**Data Sources.** Most of the information used in preparing this study came from two sources, both within USAFETAC. Studies, books, atlases, and so on were supplied by the Air Weather Service Technical Library (AWSTL or USAFETAC/DOL). Climatological data came direct from the Air Weather Service Climatic Database, through OL/A, USAFETAC—the branch of USAFETAC responsible for maintaining and managing this database.

**Related References.** This study, while more than ordinarily comprehensive, is certainly not the only source of climatological information for the military meteorologist concerned with Southern Africa. For example, USAFETAC/DS—87/034, *Station Climatic Summaries—Africa*, provides summarized meteorological observational data for several major airports in the study area. Staff weather officers and forecasters are urged to contact the Air Weather Service Technical Library for more information.

## Chapter 2

# MAJOR METEOROLOGICAL FEATURES OF SOUTHERN AFRICA

**Sea-Surface Conditions.** Ocean currents play a major role in the continent's weather. Warm waters *destabilize* the atmosphere, generally producing cumuliform clouds; cold waters *stabilize* the atmosphere, generally producing stratiform clouds. Figure 2-1 shows the currents that affect the study area, while Figure 2-2 shows mean sea-surface temperatures for January, April, July, and October.

The *Benguela Current* is cold, primarily due to upwelling as the water flows away from the coast, and partly due to flow northward from the circumpolar *West Wind Drift*. This cold water is the main reason for the extensive desert along the west coast. On rare occasions, these waters warm, bringing increased rainfall to the area (see "Southern Oscillation").

Madagascar splits the warm Indian Ocean *South Equatorial Current*, which flows north of the island and down its east coast.

The warm *Mozambique Current*, driven by the South Equatorial Current, flows down the west side of the Mozambique Channel. A number of eddies that form in the eastern sections of the channel make the flow complex.

The Mozambique Current becomes the *Agulhas Current* at about 25° S; it takes warmer waters south until it converges with the *West Wind Drift*. Speeds of the Mozambique and Agulhas Currents are higher in southern hemisphere summer with the Northeast Monsoon.

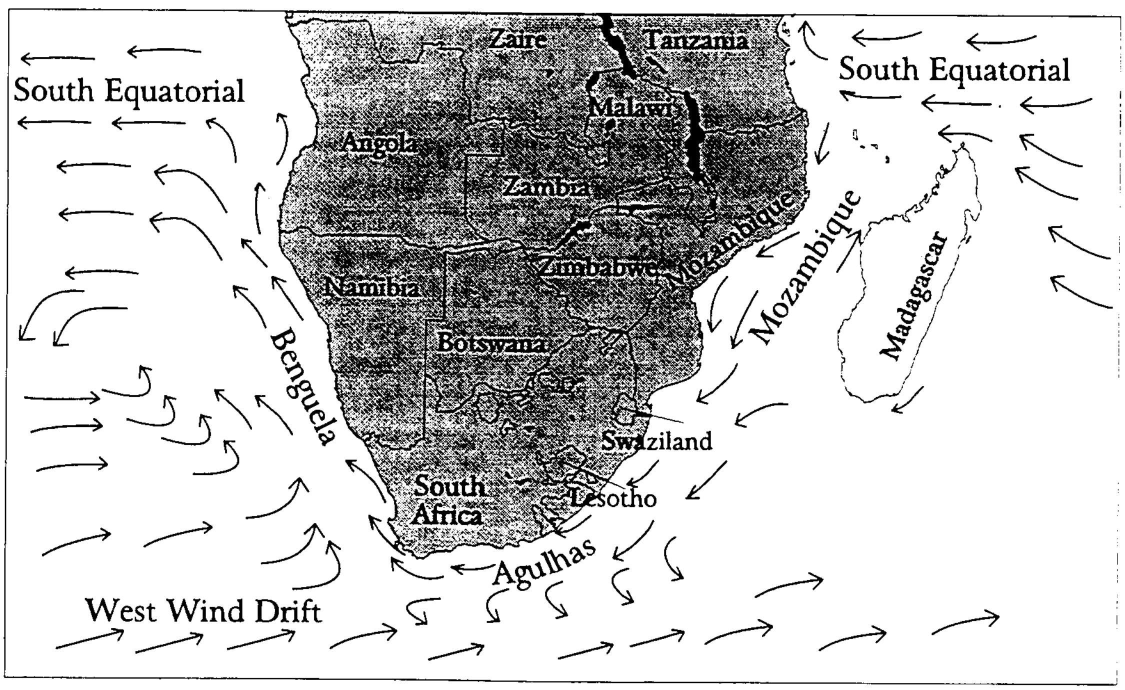



**Figure 2-1. Ocean Currents and Prevailing Direction.** Currents indicated by arrows. Currents around Madagascar vary with windflow.

"Cape Rollers," also called "Rogue Waves," are major hazards around South African coasts. Cape Rollers occur as single large waves preceded by a deep trough; they have reached extreme heights estimated to be 21 meters. Cape Rollers are a particular threat to shipping and exposed locations on the south coast.

The presence of a narrow continental shelf, strong synoptic-scale storms, and the convergence of the West Wind Drift and the Agulhas Current are believed to contribute to the formation of this phenomenon, but a strong southwest wind blowing against the Agulhas Current is a necessary condition.

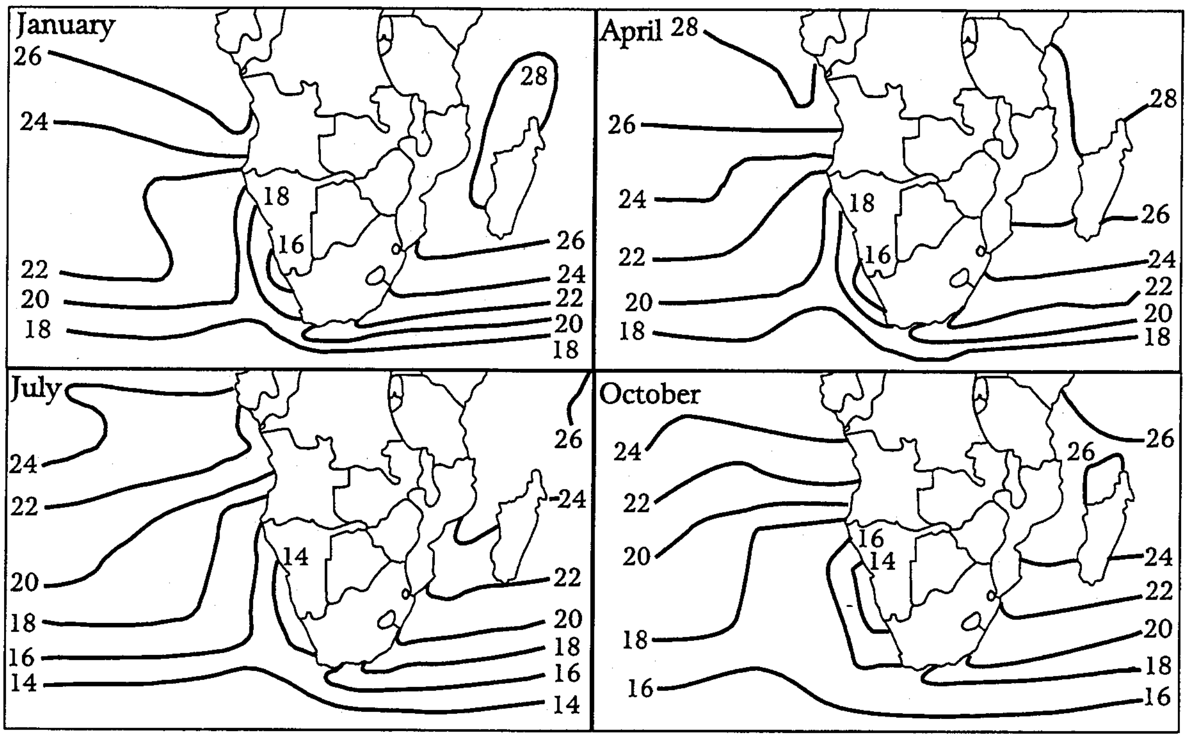



Figure 2-2. Mean January, April, July, and October Sea Surface Temperatures (° C).

**Maritime Pressure Features.** These features include the Southern Oscillation, the South Atlantic (or St Helena) High, The South Indian Ocean (or Mascarene) High, and the Mozambique Channel Low/Trough.

***The Southern Oscillation (El Niño, La Niña).*** The term "Southern Oscillation" originally referred to a sequence in which high and low atmospheric pressure systems alternated over the tropical waters of the Indian and Pacific Oceans, but it is now known to be a complex, global atmospheric/oceanic phenomena. Although the mechanism isn't fully understood, it appears to be connected to changes in the monsoon over India and the Indian Ocean and the sea-surface temperatures in the Atlantic and Indian Oceans.

Figure 2-3 shows the areas affected directly or indirectly by the Southern Oscillation. In the larger area enclosed by the solid line, precipitation from November to May is generally less in an El Niño and greater in a La Niña. The smaller area enclosed by the dot-dashed line experiences more precipitation when an "El Niño-like" event occurs in the Atlantic and raises sea-surface temperatures. These events vary interannually, but they are on a different cycle from a true El Niño; peaks are 5-6 years apart.

The Southern Oscillation is made up of two phases: a warm El Niño and a cold La Niña, with short transitions between the two. The time to complete one cycle is irregular; it varies from 2 to 10 years, but averages about 3. The El Niño phase has an average length of 18 months; in the eastern Pacific it begins in December or January (hence the term *El Niño,* which means "The Child"). In Southern Africa, the peak intensity is reached during the southern hemisphere summer (December-March).

Weather changes in both the areas shown in Figure 2-3 are based on changes in the position of the Near Equatorial Trough (NET) during southern hemisphere summer. The area enclosed by the dashed line experiences more precipitation when Atlantic sea-surface temperatures are higher (as in an El Niño) but the cycle appears to be independent of the Southern Oscillation. For example, the area experienced a precipitation maximum in 1984, a year after the end of the 1982-1983 El Niño.

There are some indications that an El Niño may cause drier conditions in the Sahel. As of the summer of 1994, more research was needed to examine these and other possible effects.

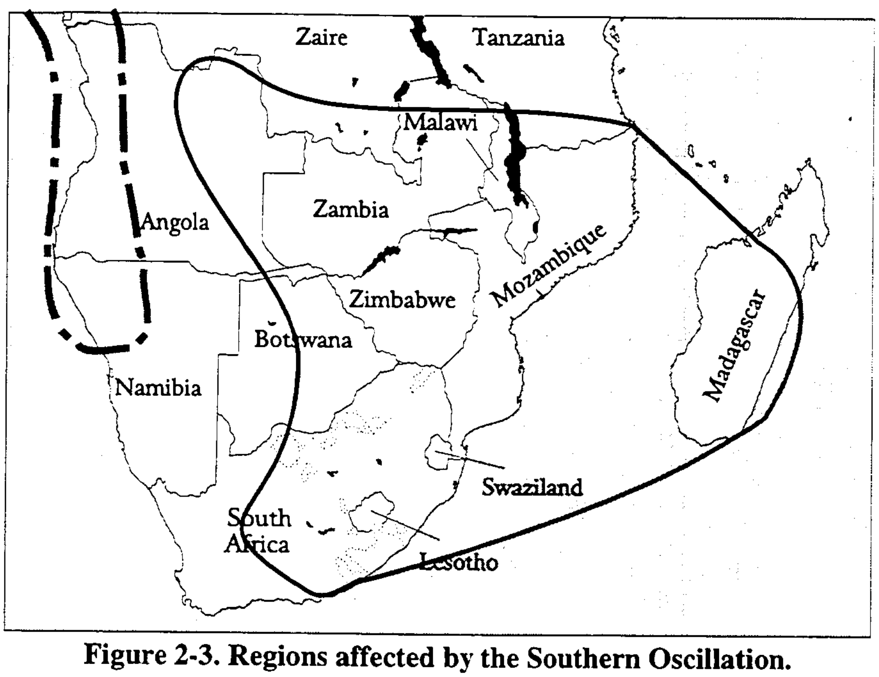



**Figure 2-3. Regions affected by the Southern Oscillation.**

***The South Atlantic (St Helena) High.*** Figures 2-4a and b (next page) show this high's mean position and sea-level pressure in January, April, July, and October. Mean pressures range from 1018 mb in March to 1025 mb in September. The cell migrates northwestward from 32° S, 8° W in January to 26° S, 12° W in July. Surface wind speeds average 13 knots north of the cell, and 25 knots to the south along the mid-latitude storm track.

The high slopes equatorward with height. Note that it is stronger and farther north in winter than in summer, the opposite of its counterpart in the northern hemisphere. It is caused by differential heating of the continents and oceans, which would be strongest in January in the southern hemisphere. Since, most of the Earth's landmass is in the northern hemisphere, however, this affect is overwhelmed.

Flow from the South Atlantic High plays a major role in determining the weather across much of the study area. For example, it forms convection in south-central Africa where the flow meets South Indian Ocean flow, forming the Congo Air Boundary. The eastern limb of the cell remains relatively fixed along the southwest coast where there is strong subsidence and a low-level inversion. Maximum coastal subsidence, at about 25° S, prevents most frontal systems from penetrating northward along the southwest coast. Flow around the eastern end of this high produces the cold Benguela Current, which further stabilizes the coastal area.

***The South Indian Ocean (Mascarene) High.*** Figures 2-4a and b also show this high's mean position and sea-level pressure in January, April, July, and October. Mean pressure ranges from 1021 mb in April to 1028 mb in August; pressure can exceed 1040mb in winter. Movement is mainly east-west from 30° S, 87° E in January to 29° S, 65° E in July. Like the South Atlantic High, it is stronger and farther north in the winter, than in summer. This high also slopes equatorward and westward with height.

The high's large east-west movement results in a seasonal variation of increased stability and more frequent inversions in the southern hemisphere winter over Madagascar and southeast Africa. Since the high is closer to the coast, it produces a trade-wind inversion that is lower in the southern hemisphere winter. The depth of the southeasterly trade-winds off the coast varies from 2,000 to 4,000 meters.

In central Africa, the flow from the South Indian Ocean High meets flow from the South Atlantic High to produce the Congo Air Boundary. The South Indian Ocean High is the main steering mechanism for tropical cyclones affecting Madagascar and southeast Africa.

***The Mozambique Channel Low/Trough.*** This is a semipermanent feature over the Mozambique Channel (see Figures 2-4a and b). It develops in the wake of Madagascar's mountainous terrain with easterly flow from the South Indian Ocean High and is reinforced by warm sea surface temperatures. It is strongest in the summer (December to February); in January and February it lies along the NET and actually pulls the NET southward into the channel. It is less marked from May to September as the South African High extends to the east, joining the South Indian Ocean High. Lows can develop any time of the year along the trough when frontal systems affect the area, but they are temporary.

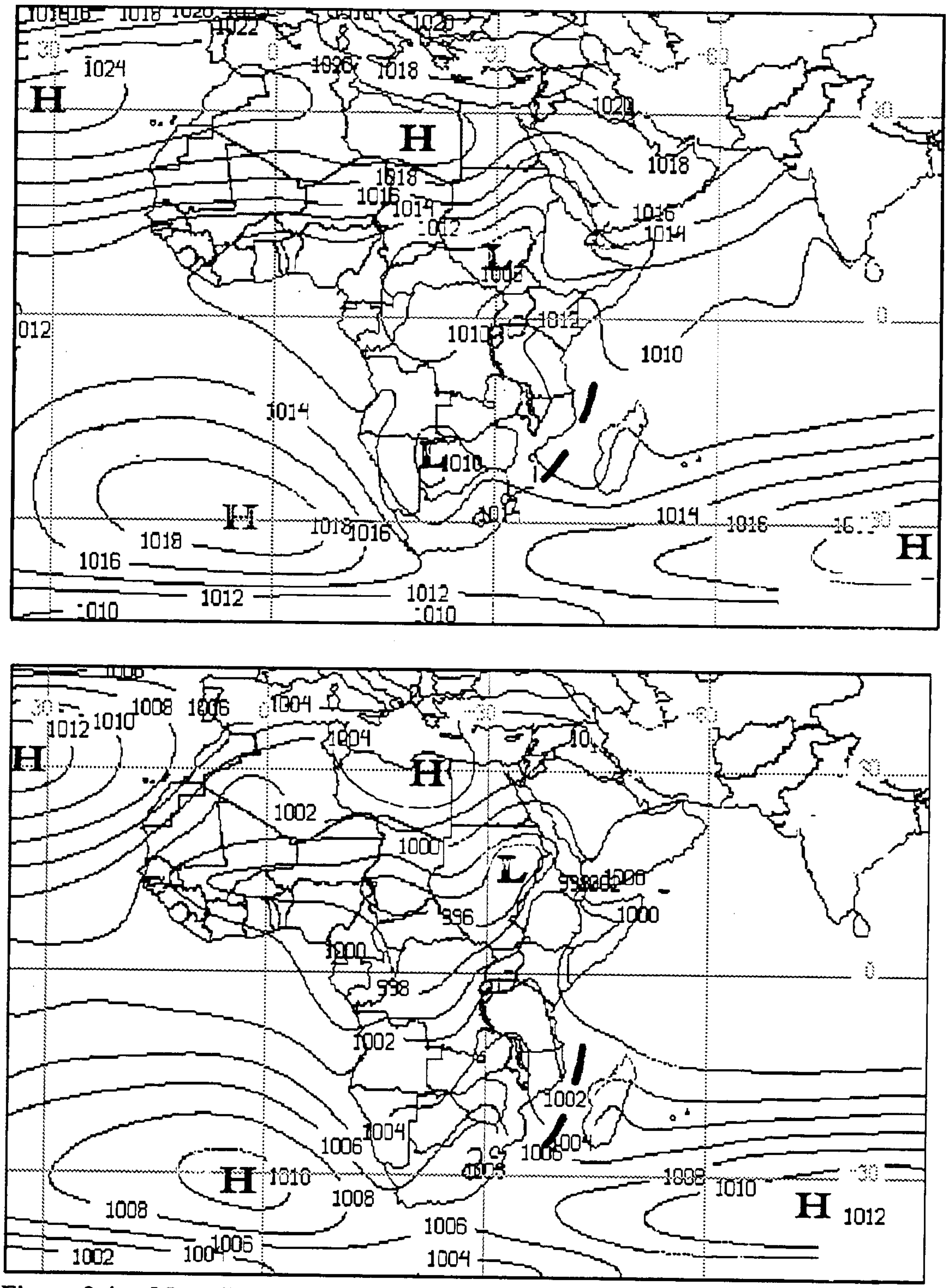



**Figure 2-4a. Mean January and April Positions of Major Pressure Systems Affecting Southern Africa.**

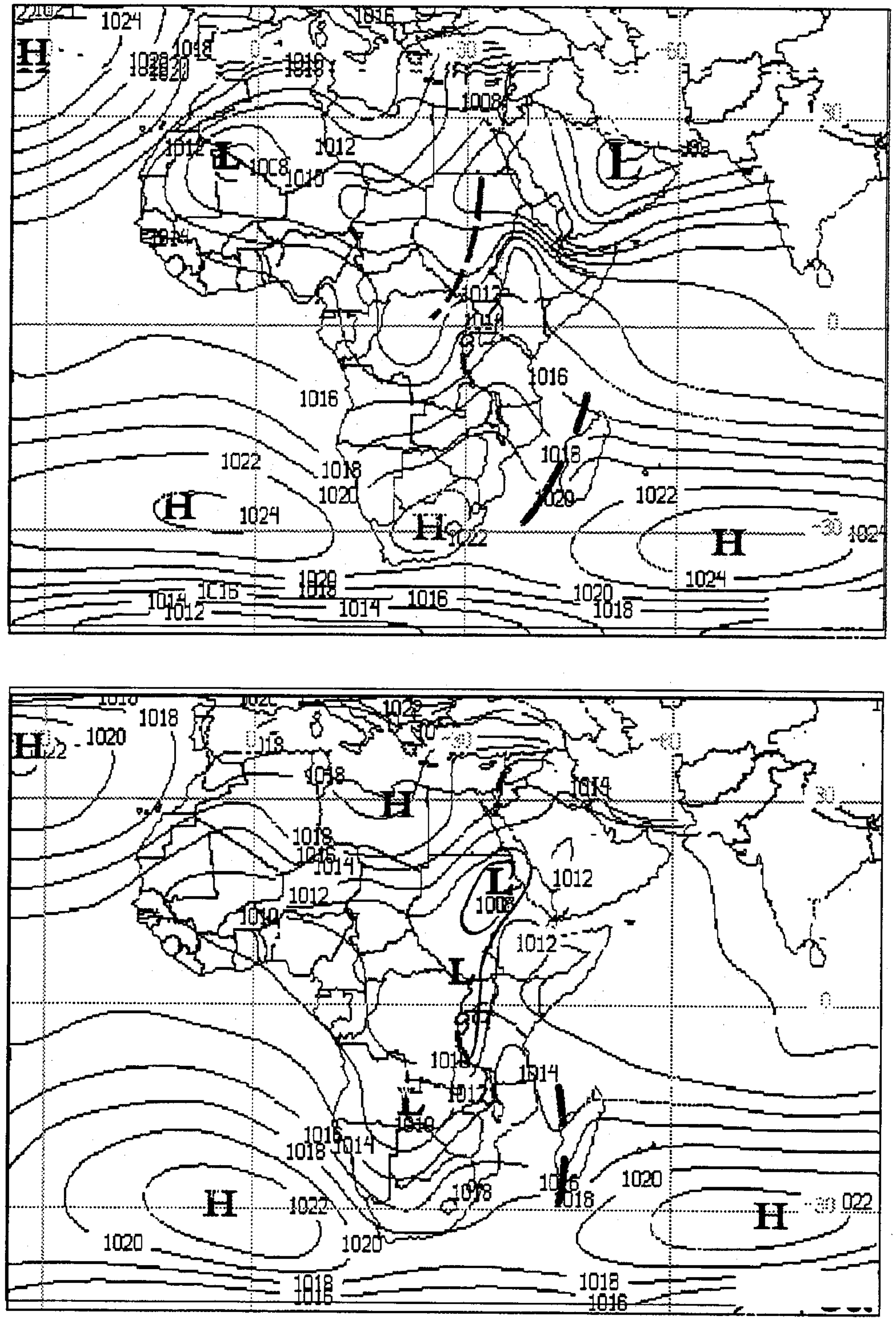



**Figure 2-4b. Mean July and October Positions of Major Pressure Systems Affecting Southern Africa.**

**Continental Pressure Features.** The following continental pressure systems affect Southern Africa; they are also shown in Figures 2-4a and b.

***The South African High*** is a continuation of the subtropical belt of high pressure over land between the South Atlantic and South Indian Ocean Highs. It is often an extension of ridging from the South Indian Ocean High. It can be present throughout the year, but shows on the mean pressure chart only during the southern hemisphere winter (see Figure 2-4b, July). Strong radiative cooling enhances its surface strength, but day-to-day position and strength vary as deep polar troughs enter South Africa. The cell does move northwards enough to bring westerlies over southern Africa. The col between it and the South Atlantic High is usually over the Great Escarpment in Namibia. The South African High is the primary reason for the arid/semiarid conditions in the southern African interior. It weakens significantly during the summer, allowing some precipitation. Its strength during the southern hemisphere summer directly influences how much precipitation southern Africa gets during its wet season.

***The Zaire/Zambian Low*** is primarily a thermal low that forms along the Congo Air Boundary where outflow from the South Atlantic and South Indian Ocean Highs meet; it moves north-south with this convergence zone. Present year-round, it shows on the mean pressure charts only during the southern hemisphere spring and summer (see Figures 2-4a and b, January & October). It averages 1006 mb in January over the Upper Veldt to the northwest of Lake Kariba. During April, it shifts northward into south central Zaire and weakens. By May it has become just a weak, broad area of low pressure. It moves back to the south and intensifies from August to October.

**Monsoon Climate**. The term "monsoon" (from the Arabic *mawsim*, "seasons") is commonly applied to those areas of the world where there is a seasonal reversal of prevailing winds, but the generally accepted definition of a monsoon climate includes satisfaction of all four of the following criteria (after Ramage, 1971); Figure 2-5 shows the extent of the "monsoon climate" across Africa, according to Ramage's criteria.

• Prevailing seasonal wind direction changes by at least 120 degrees between summer and winter.

• Summer and winter mean wind speeds both equal or exceed 10 knots (5 meters/sec).

• Wind directions and speeds must remain steady.

• No more than one system consisting of a low and a high may occur during January or July in any 2-year period within a 5-degree square surrounding the area.

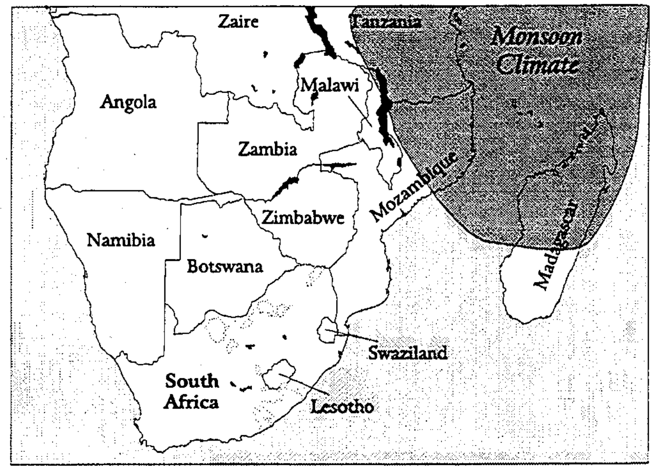



**Figure 2-5. Extent of the Monsoon Climate (shaded area) Across Southern Africa.**

***The Near Equatorial Trough (NET)***, also called the "Intertropical Convergence Zone" (ITCZ) and the "Meteorological Equator," is caused by the convergence of the outflows from the northern and southern hemispheres' subtropical highs. Convection can be frequent, but there is rarely a continuous line along the NET axis. "Trade-Wind Trough" (or "Trade-Wind Convergence Zone") and "Monsoon Trough" are common terms that pertain to specific forms of the NET. Trade-Wind Troughs occur with confluence between northeasterly and southeasterly trade-wind flow. Most associated cloudiness occurs along the axis of confluence. Monsoon Troughs are characterized by a directional shear zone, with westerlies on the equatorward side and easterlies on the poleward side. Most associated cloudiness occurs equatorward of the trough.

A Monsoon Trough forms west of the Great Rift Valley year-round, produced by the convergence of outflows from the Azores and South Atlantic Highs. Dry, subtropical Saharan air is to the north, with moist, equatorial Atlantic air to the south. The boundary between the air masses is also called the "Intertropical Discontinuity." The trough slopes to the south with height; convection develops well south of the surface trough. This Monsoon Trough follows the sun's annual movement, trailing it by about 6 weeks. The trough's northward movement is more gradual than its southward movement. It is farthest north in July and August.

Another Monsoon Trough forms over the Great Rift Valley from December to March, the result of convergence of the Northeast Monsoon flow with South Atlantic High outflow. This trough is oriented generally north-south along the mountain ranges; it is sometimes referred to as the "Great Rift Heat Trough." High terrain increases lifting and convection while making the surface position of the trough less well-defined.

From December to February, a trade-wind trough forms over East Africa with a Monsoon Trough over Madagascar and the South Indian Ocean. Both are produced by convergence of the Northeast Monsoon and the South Indian Ocean High. The Monsoon Trough over the South Indian Ocean is a source of tropical cyclones.

From June to September, a secondary trough can develop in a buffer zone near the equator, where the winds switch from southeasterly to southwesterly. This cloud band is referred to as the "Southern Equatorial Trough" (SET) and is normally in the central Indian Ocean. Organized convective disturbances in the SET move west and occasionally reach East Africa.

Fronts passing to the south affect the NET during the southern hemisphere summer (December to February). Convection increases with an approaching front but is reduced afterward when high pressure moves into or ridges into the southern African interior. The NET can move southward 5 degrees of latitude with the approaching system and can then be driven northward by the high pressure behind it. Strong cold fronts that penetrate as far north as Zambia dissipate the convection until the front moves off the subcontinent. Conditions over southern Africa temporarily become as dry as in the winter.

Figures 2-6a-h show each NET monthly position (dashed line) with the zone of associated convection produced by it (solid line), along with representative satellite photos. The associated convection zones average two organized convective systems at least 200 km in size per each 1-degree grid square. These systems are "cloud clusters" (individual cells embedded in a common cirrostratus canopy); they are responsible for most of the rainfall received. This criterion is also in agreement with available satellite cloud composites. The number of occurrences increases towards the center of each area. The monthly and yearly variability is greatest on the edges. The satellite photos are NOAA Mercator projections of polar orbiter data.

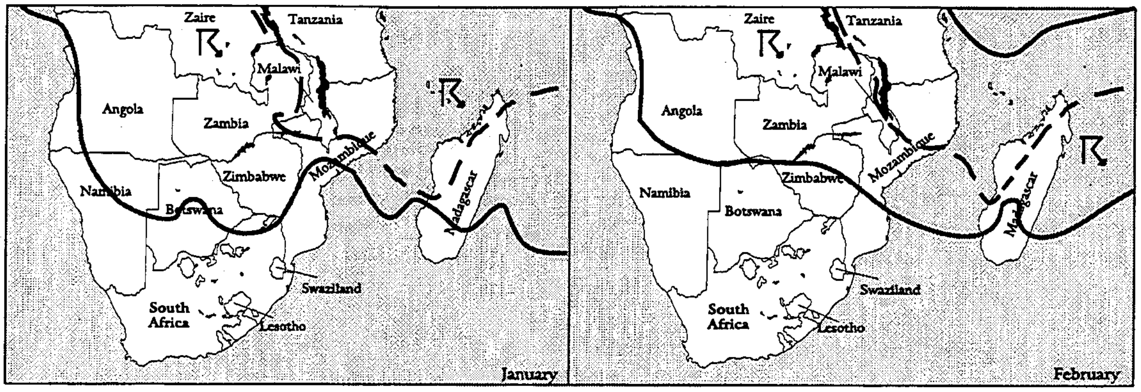



**Figure 2-6a. Mean January and February Positions of NET (dashed) and Associated Convection (solid).** Convection is at a maximum near Lake Tanganyika.

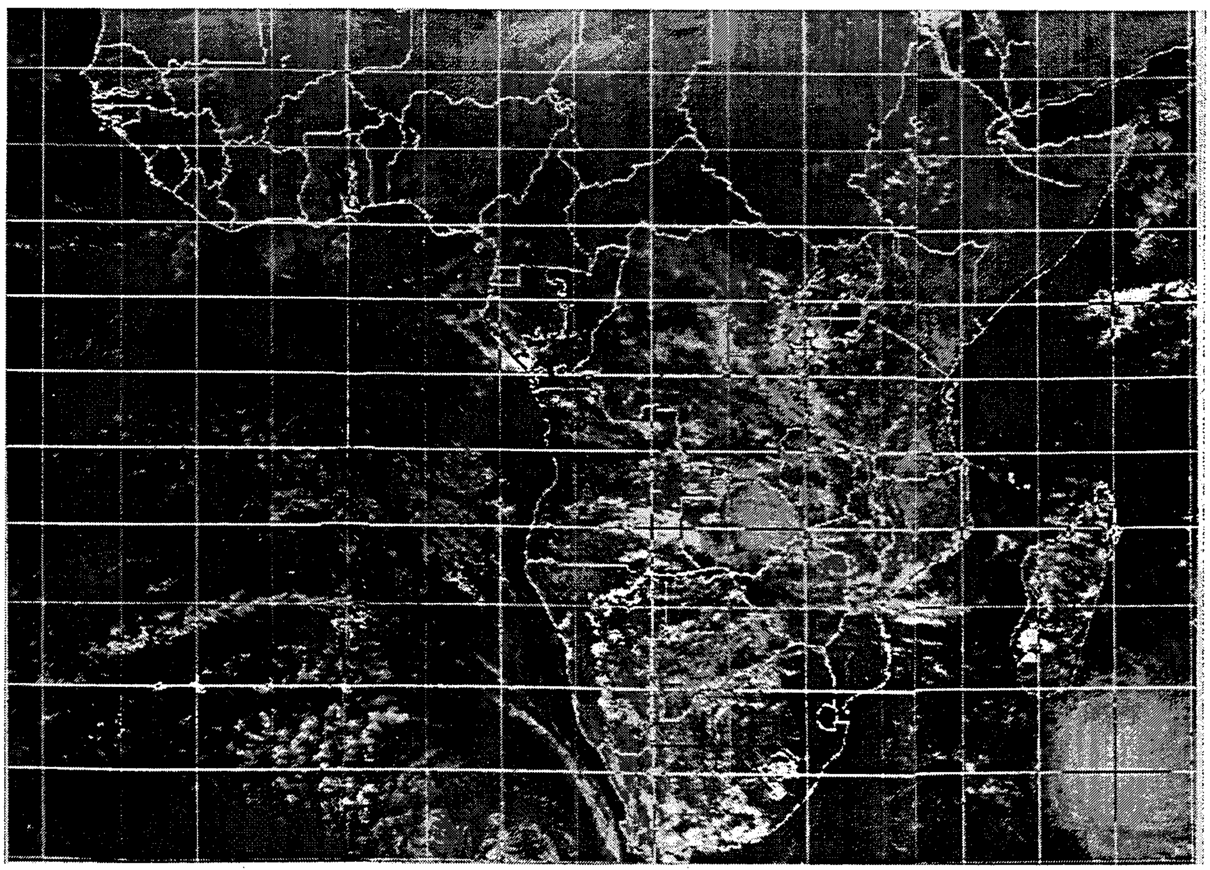


**Figure 2-6b. NOAA Visual Image, 31 January 1989.** Most convection is in the Southern Hemisphere except for the Gulf of Guinea. Tropical cyclones affect Madagascar. (NOAA/NESDIS).

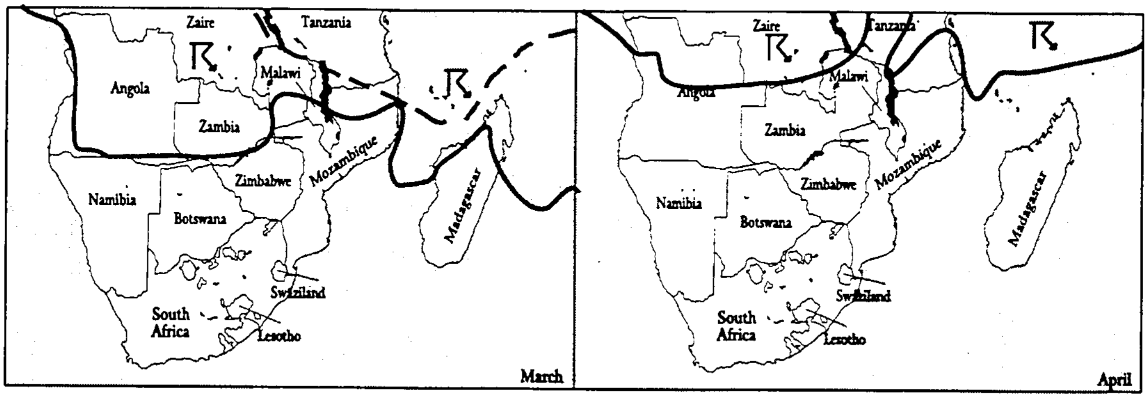



**Figure 2-6c. Mean March and April Positions of NET (dashed) and Associated Convection (solid).** Convection is at a maximum near Lake Tanganyika.

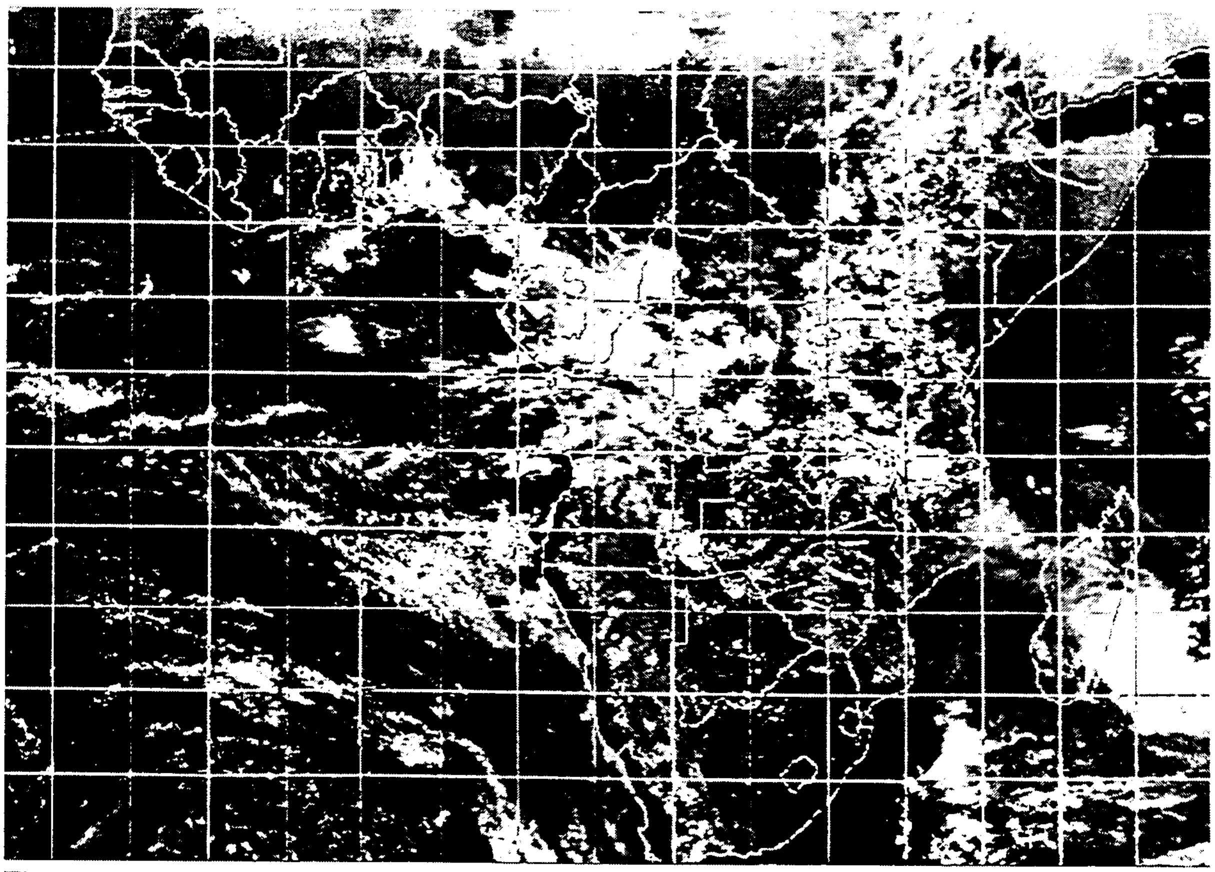


**Figure 2-6d. NOAA Visual Image, 28 March 1989.** Convection has started to shift northward, particularly along the Gulf of Guinea coast. Tropical cyclones affect Madagascar.

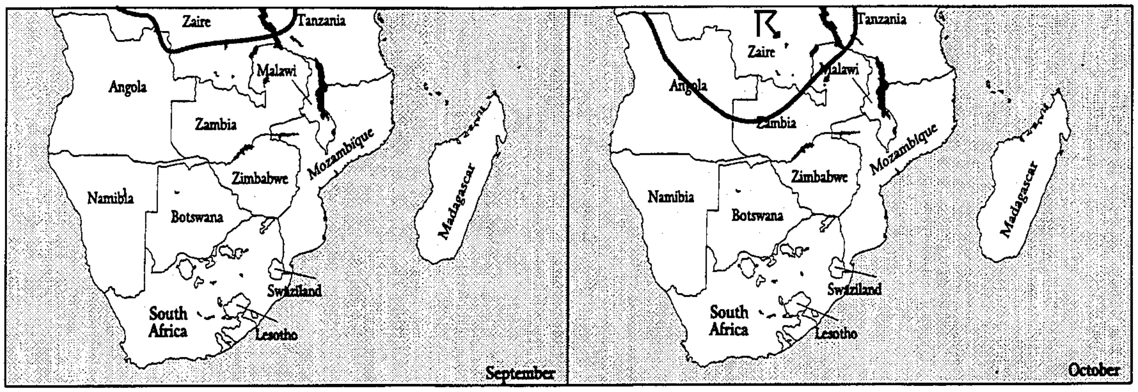



**Figure 2-6e. Mean September and October Positions of NET (dashed) and Associated Convection (solid).** Convection is at a maximum over northern Zaire.

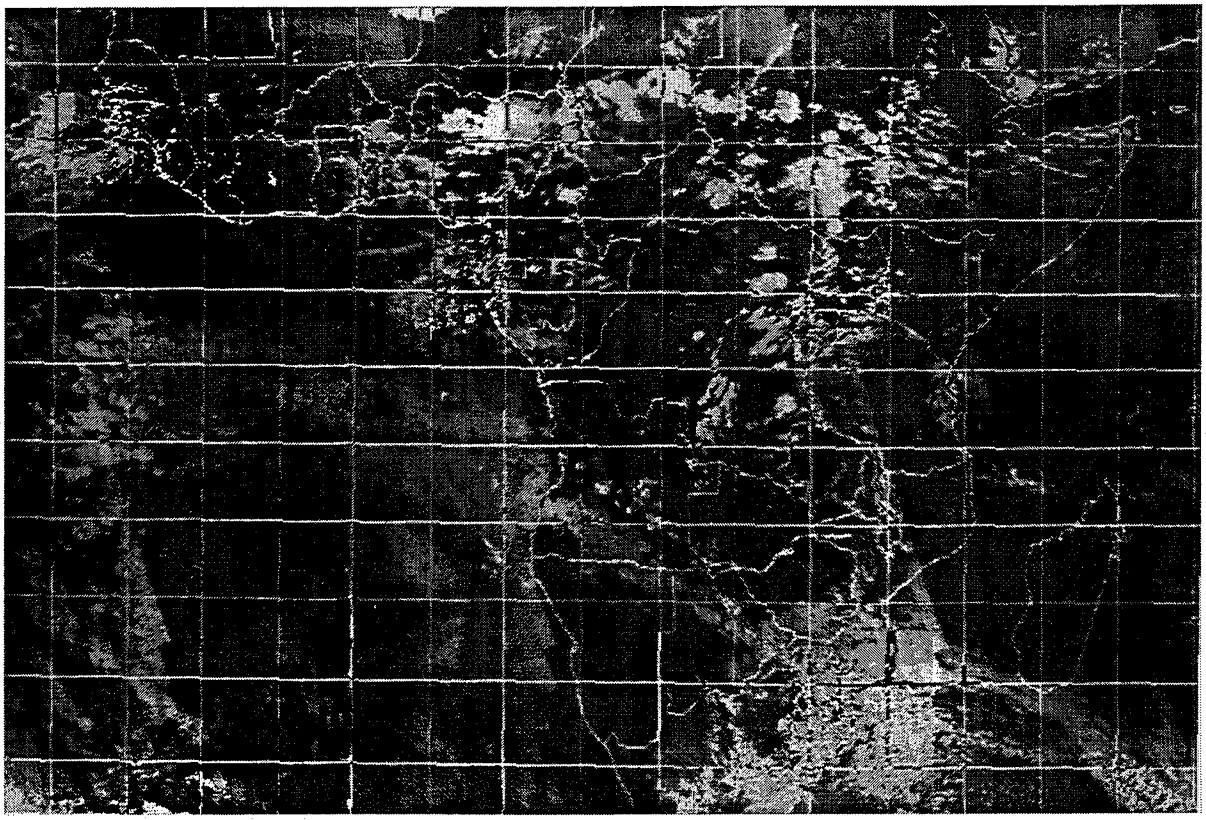


**Figure 2-6f. NOAA Visual Image, 2 September 1988.** Some convection moves south into the region. A frontal system is seen in the south. Onshore flow causes coastal stratus.

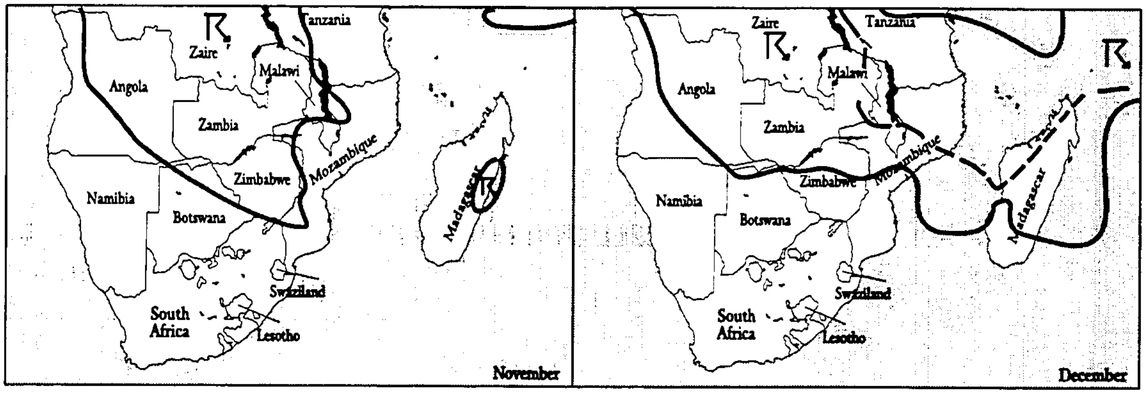



**Figure 2-6g. Mean November and December Positions of NET (dashed) and Associated Convection (solid)** Convection is again at a maximum near Lake Tanganyika.

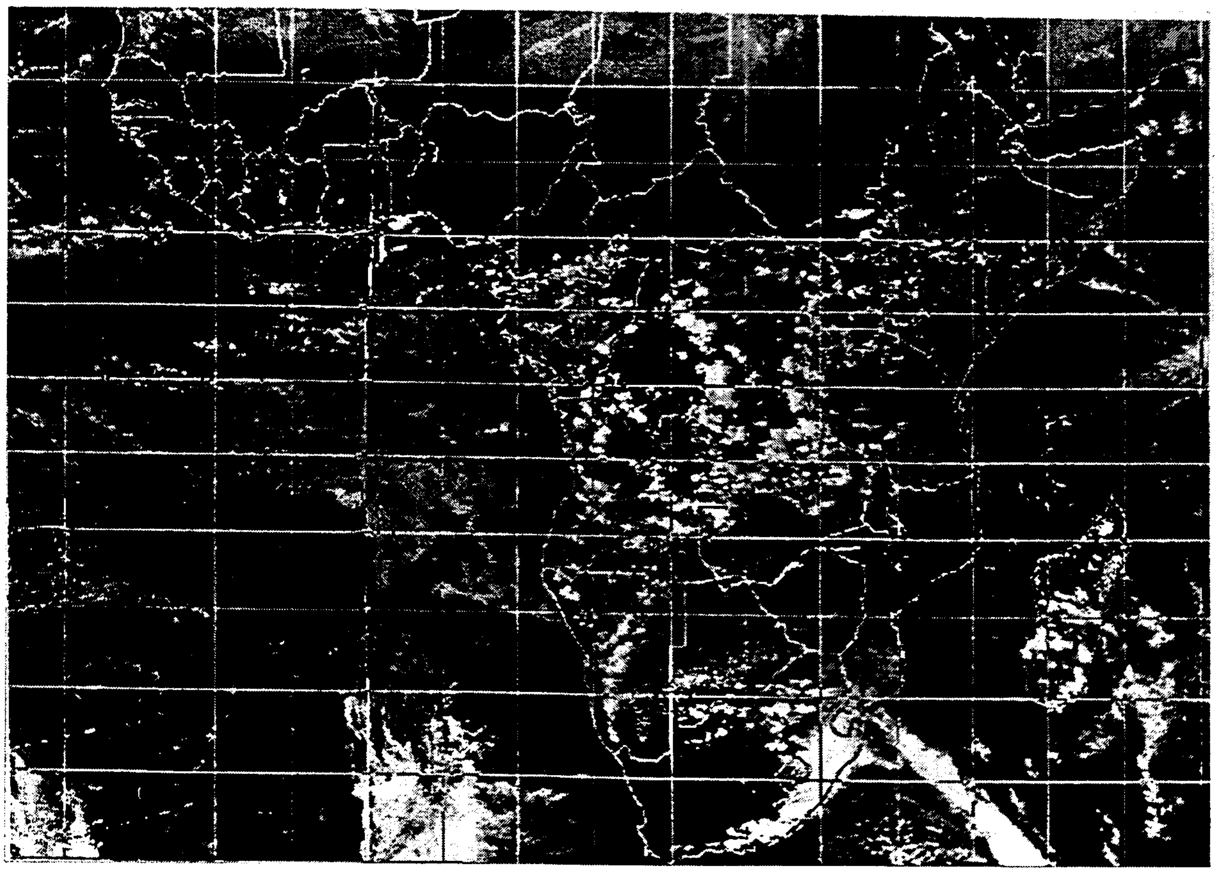


**Figure 2-6h. NOAA Visual Image, 15 November 1988.** Most of the convection has shifted into the Southern Hemisphere. Stratus forms behind a front along the southeast coast.

**The Northeast Monsoon** originates over the Asian landmass, but the air is modified before reaching the region by either the Arabian Sea or the Ethiopian Highlands. Northeasterly winds affect East Africa and northwestern Madagascar during the southern hemisphere summer because the NET is south. The Northeast Monsoon moves into the area from October to December; it is strongest in January and February. It weakens and is replaced by the Southeast Monsoon from March to May. The Northeast Monsoon is normally not as strong as the Southeast Monsoon, but wind speeds are above 50 knots below 2,400 meters once every other year near the mountains in Kenya. Figure 2-7 shows the mean meridional flow at the equator in January; the Northeast Monsoon is evident along the East African coast with an average speed of 10 knots.

**The Southeast Monsoon** develops in response to the large thermal trough that lies over the Asian landmass during the northern hemisphere summer. The flow originates from the South Indian Ocean High, producing southeasterly winds over Madagascar and Mozambique, southeasterly to southerly winds over Tanzania, and southerly to southwesterly winds over Kenya and Somalia. As a result, countries near the equator refer to it as the "South Monsoon," while countries north of the equator refer to it as the "Southwest Monsoon."

Whatever the local name, it begins in March and moves northward through May as the Northeast Monsoon weakens and the NET moves north. It is strongest from June to September, usually ending during November as the Northeast Monsoon drives the NET southward. The top of the Southwest Monsoon layer is usually between 3,600 and 4,200 meters. The Somali Jet is often present with the Southeast Monsoon. Figure 2-8 shows the mean meridional flow at the equator in July; the Southeast Monsoon is evident along the African coast with an average speed of 30 knots.

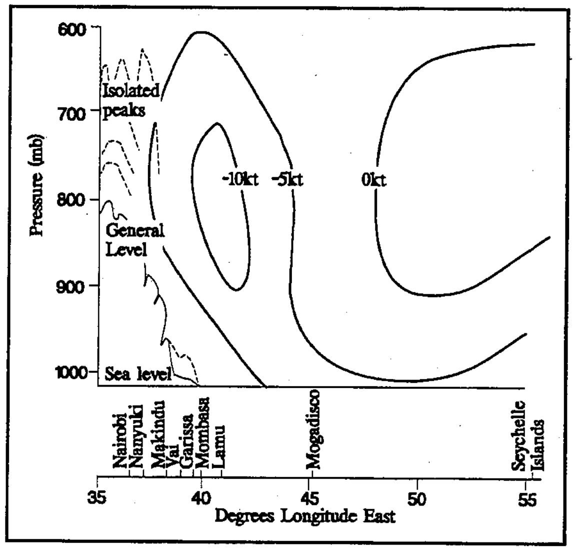



**Figure 2-7. Mean Meridional Flow at the Equator in January Showing Northeast Monsoon.** Negative values indicate flow is from the north.

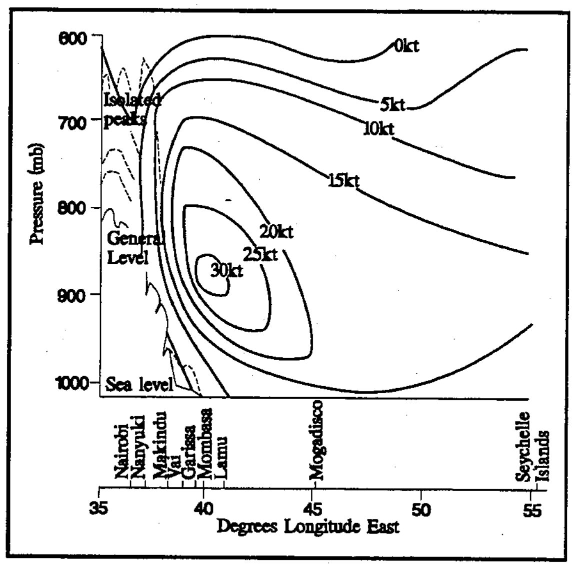



**Figure 2-8. Mean Meridional Flow at the Equator in July Showing Southeast Monsoon.** Positive values indicate flow is from the south.

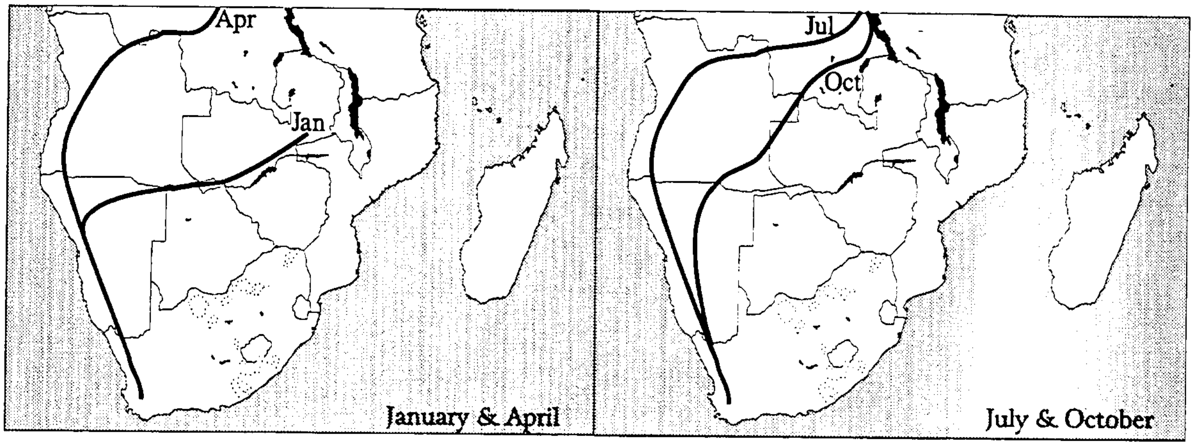



**Figure 2-9. Annual CAB Positions.** The northeastern end of the January position ends at the NET.

**Congo Air Boundary (CAB).** This boundary is produced by convergence of South Atlantic and South Indian Ocean High outflow. It is also variously called the "Zaire Air Boundary," "Central African Convergence Line," "Inter-Oceanic Confluence," and "African Equatorial Front." Figure 2-9 shows its locations throughout the year. It technically extends north to the NET, but the Ethiopian Highlands effectively block the southeasterly flow from April to October, ending the boundary in southern Sudan. The southern end of the boundary normally lies over the escarpment across Namibia and South Africa.

From May to September, the South Atlantic High outflow is cooler and moister than the South Indian Ocean and South African High outflows, which are modified crossing the desert interior and the Rift Valley. The hot, dry air flows over the South Atlantic air, producing stability. The Atlantic air mass doesn't become deep enough to produce precipitation.

From October to April, instability and precipitation are present, particularly in the Atlantic air mass. The outflow from the South Atlantic High recurves in this season, becoming northwesterly over the Congo River Basin. The Atlantic air mass is warmed crossing the basin, providing the needed instability. Some cloudiness and precipitation occur south of the CAB in the drier Indian Ocean air mass, but it is more limited to scattered shower activity. The section of the CAB over the escarpment remains dry year-round.

The seasonal northward movement of the boundary can be gradual or abrupt. Convection stops gradually in some years, while other years see a strong invasion of cold air drive the CAB northward until the next wet season. The seasonal southward movement has frequent, rapid displacements from the mean position early in the wet season over southern Africa.

Cloudiness can become oriented more NW-SE with fronts to the south in the summer. The "linkage" creates more instability and increased convection for 3 to 4 days over southern Africa. Moist air over Zaire is pulled farther south. If a polar high moves into southern Africa behind the front, CAB convection can be forced northwards.

**Trade-Wind Inversions.** The SouthAtlantic andIndian Ocean Highs slope toward the equator with height, producing these subsidence inversions over the trade winds. They are strongest over the northwest and southwest coasts of Africa. Relative humidity is greater than 70% below the inversion and less than 50% above. Inversions result in stable conditions, preventing precipitation and trapping moisture in the lower layer.

The inversion's mean height along and near the escarpment of southern Angola, Namibia, and South Africa is 500 meters; it gradually rises northward toward the tropics. The inversion keeps the moisture trapped in the lower layer until reaching the tropics. Areas with strong instability force the inversion higher; its height, therefore, is usually lower in the winter than in the summer and lower over water than land.

Over the east coast of South Africa, the inversion from the South Indian Ocean High is at about 2,000 meters in summer and 1,000 meters in winter. Its strength is much weaker than over the southwest coast. This inversion is a factor in producing the dry winter over the South African interior when it is at about 2,000 meters. It can also be present during the summer, but it is weaker and higher (3,000 meters.

Trade-wind inversions also occur over the Southeast and Northeast Monsoons. Mean inversion heights are 1,500 meters over water, rising to 3,300 meters over Nairobi.

**Circumpolar Trough.** The topography of the Antarctic and land/sea temperature difference produces three favorable areas for semipermanent low pressures around the Antarctic landmass (see Figure 2-10). These lows show little variation from season to season; hence the name "Circumpolar Trough." A strong temperature gradient is present year-round between the Antarctic air mass and the surrounding oceanic air masses; this gradient produces persistent zonal mid- and upper-level flow patterns over the polar regions. Its primary influence on southern Africa is to act as a sink for low-pressure systems crossing the South Atlantic; they generally move east-southeast (see Storm Tracks). Figure 2-11 is a satellite image of the trough south of Africa. In this example, the low is near 60° S, 40° E. Lows crossing the South Atlantic tend to turn toward, and move into, the trough in this area.

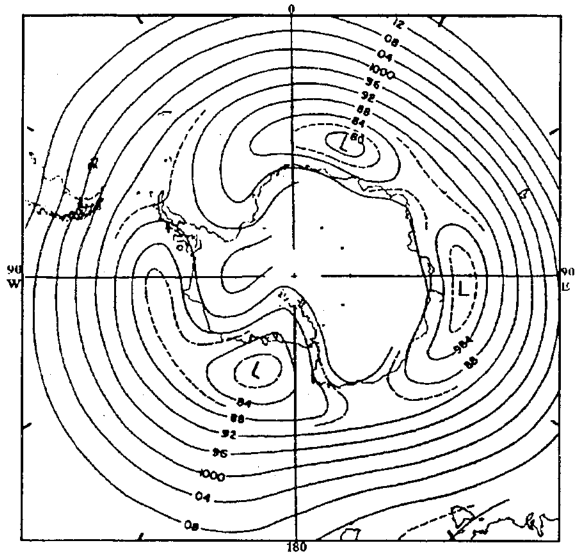



**Figure 2-10. July Mean Sea-Level Pressure Around Antarctica Showing Circumpolar Trough.**

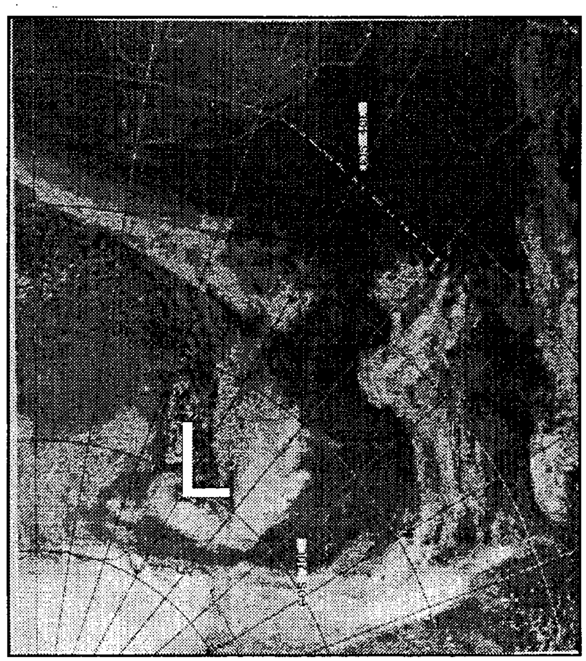



**Figure 2-11. NOAA Nighttime IR Image of Circumpolar Trough and Southern Africa, 15 July 1988.**

**Jet Streams.** Three jet streams affect this region: the Polar Jet (PJ), the Subtropical Jet (STJ), and the Somali Jet.

***Polar and Subtropical Jets.*** The PJ's positions and movements control cold air advection and mid-level direction for developing cyclones; the STJ provides steering, shear, and outflow in the upper levels. Figure 2-12 shows the mean jet positions in January and July.

The southern hemisphere's jets are quite different from those in the northern hemisphere; there is just one band of maximum winds during most of the year. Winds circle the globe uninterrupted between the land masses and Antarctica except near the Andes Mountains in South America. Both an STJ and a PJ show in the mean only during the winter.

Mean southern hemisphere PJ positions and intensities vary little throughout the year. The mean position in summer (January) is actually slightly north of the winter position. Average height is 200 mb. Mean winds are westerly at 90 knots in January and westerly at 80 knots in July. Speeds normally increase crossing the Atlantic. Southern hemisphere jets are not as strong as their northern hemisphere equivalents due to the lower temperature contrasts over the oceans; they are, however, more persistent. The flow south of Africa is undisturbed by land and is often zonal.

The STJ is usually indistinguishable from the PJ. A separate wind maximum is evident during the winter (see Figure 2-12, July), crossing Africa at 30° S. Maximum winds average 60 knots. The jet has been observed to extend as far north as Botswana.

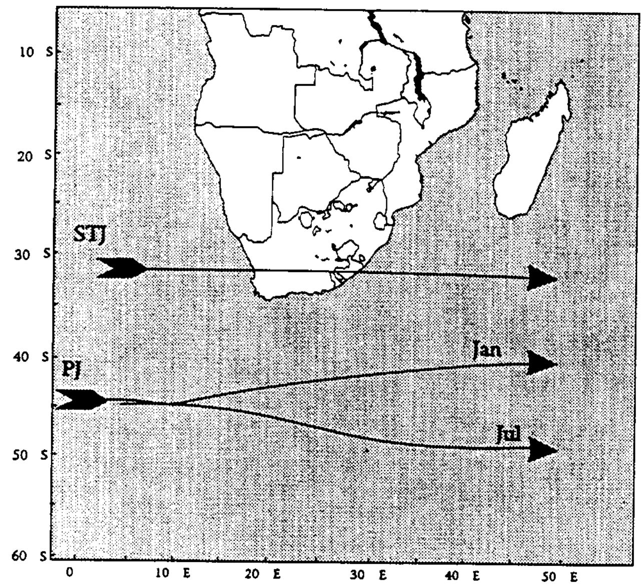



**Figure 2-12. Mean January and July Positions ofthe Polar Jet (PJ) and Subtropical Jet (STJ).** There is no mean STJ in January.

***Somali Jet.*** From April to late October, Southeast Monsoon flow from the South Indian Ocean High is compressed into a high-speed jet core along the eastern edge of Africa. The core normally passes just north of Madagascar heading to the northwest, enters Africa over southern Kenya, and turns to the northeast out across Somalia. The core is usually at about 600 meters MSL over the open Indian Ocean. Over land, the jet is normally between 1,200 and 2,100 meters MSL, with the average being 1,500 meters MSL.

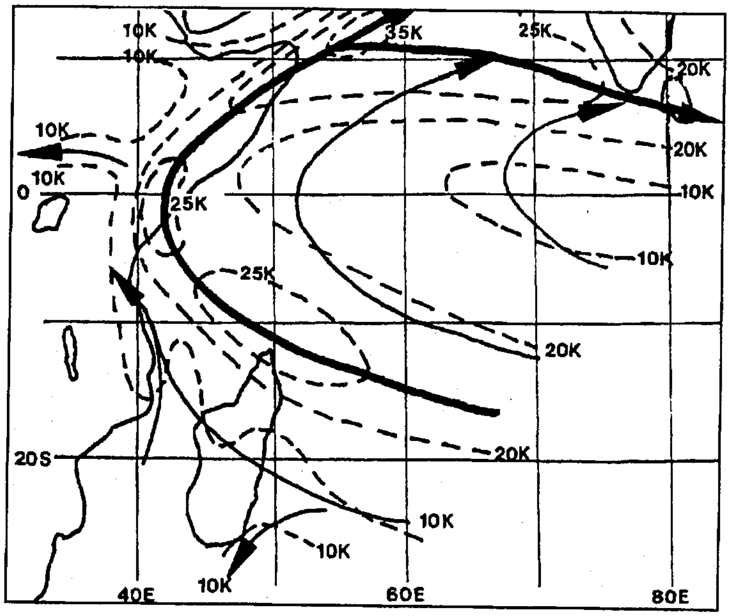



**Figure 2-13. Mean July Monthly Airflow, 900 meters (3,000 feet).** The thicker lines indicate the mean jet core. Dashed lines are isotachs in knots.

Figure 2-13 shows the mean July monthly airflow directions and speeds at 900 meters across the western Indian Ocean basin.

The Somali Jet, also called the "East African Jet," has mean core speeds between 25 and 40 knots. This jet normally strengthens from April to July and gradually weakens from August to October. Highest wind speeds are near the equator across Kenya and Somalia; speeds of 100 knots have been reported. These extreme speeds may be due to southern hemisphere polar surges.

Figure 2-14 shows the maximum wind speeds across the area between 600 and 2,400 meters MSL associated with the Somali Jet. The core of this jet is usually 550 to 900 km long, 180 to 370 km wide, and 2 km deep. Height and speed variations in single or multiple low-level jets are primarily produced by synoptic-scale surges.

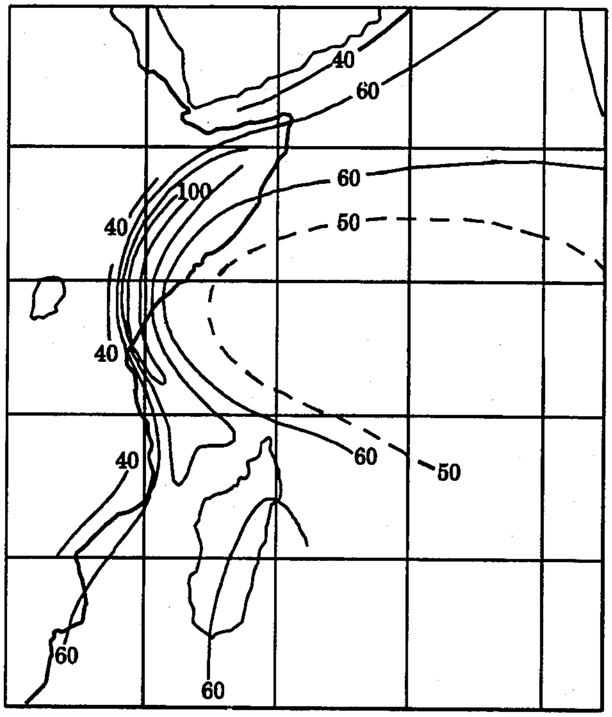



**Figure 2-14. Maximum Wind Speeds Associated with the Somalia Jet (knots).**

Individual cores can be tracked moving downstream through the region, data permitting, and can cross Madagascar and Kenya within 24 hours. Figure 2-15 shows a vertical cross-section of the jet across Kenya on 13 June 1966. Strong wind shear outside the core produces moderate turbulence.

Like most low-level jets, the Somali Jet shows a marked diurnal variation. Peak core speeds occur near dawn, with minimum core speeds in the late afternoon. Surface wind speeds beneath the core are just the opposite; minimum speeds are at dawn and maximum speeds are in the mid-afternoon.

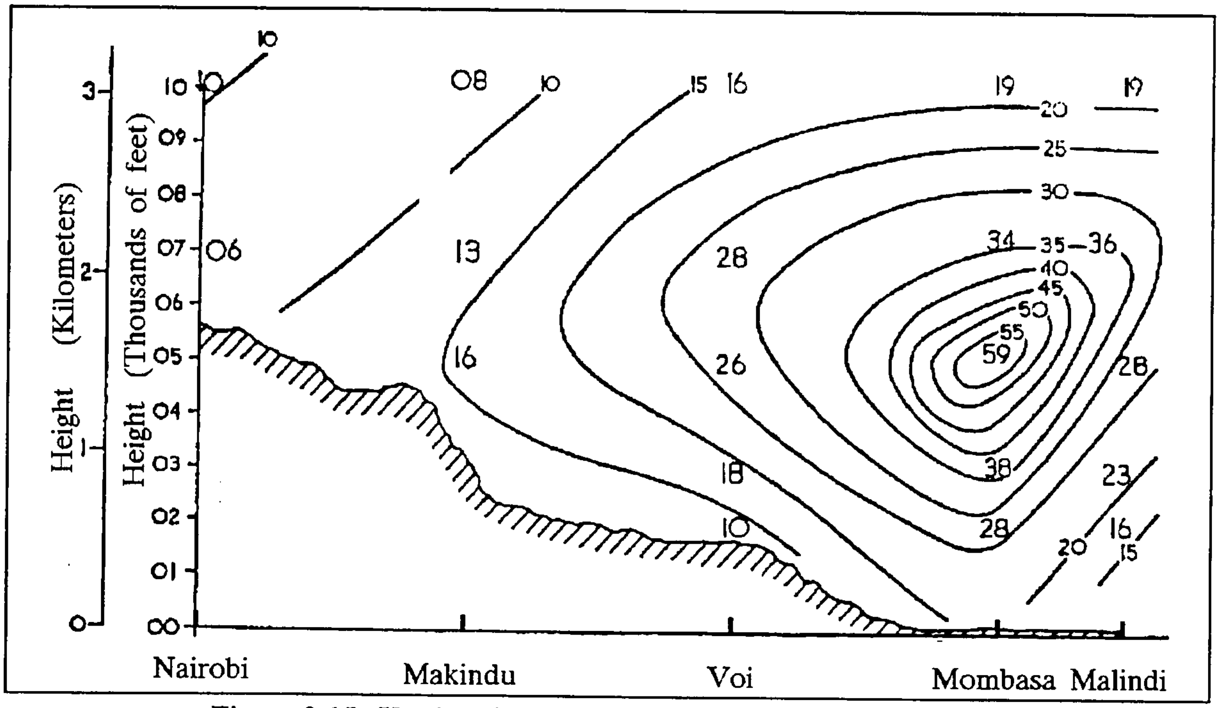



**Figure 2-15. Vertical Cross-Section Over Kenya, 13 June 1966.**

**Mid- and Upper-Level Flow Patterns.** Figures 2-16 through 2-19 show January, April, July, and October streamline flow at 850, 700, 500, and 200 millibars over the entire study area. The 850-mb level is usually used as the surface across the interior plateaus of southern Africa.

**The Subtropical Ridges** are upper-level features north and south of the equator over Africa with easterly flow between them. Moving north-south with the sun, they are at their northernmost positions in July and at their southernmost positions in January. These features are important in that they provide outflow for NET convection. See Figures 2-16 through 2-19, 200 mb, for the locations of the southern hemisphere ridges.

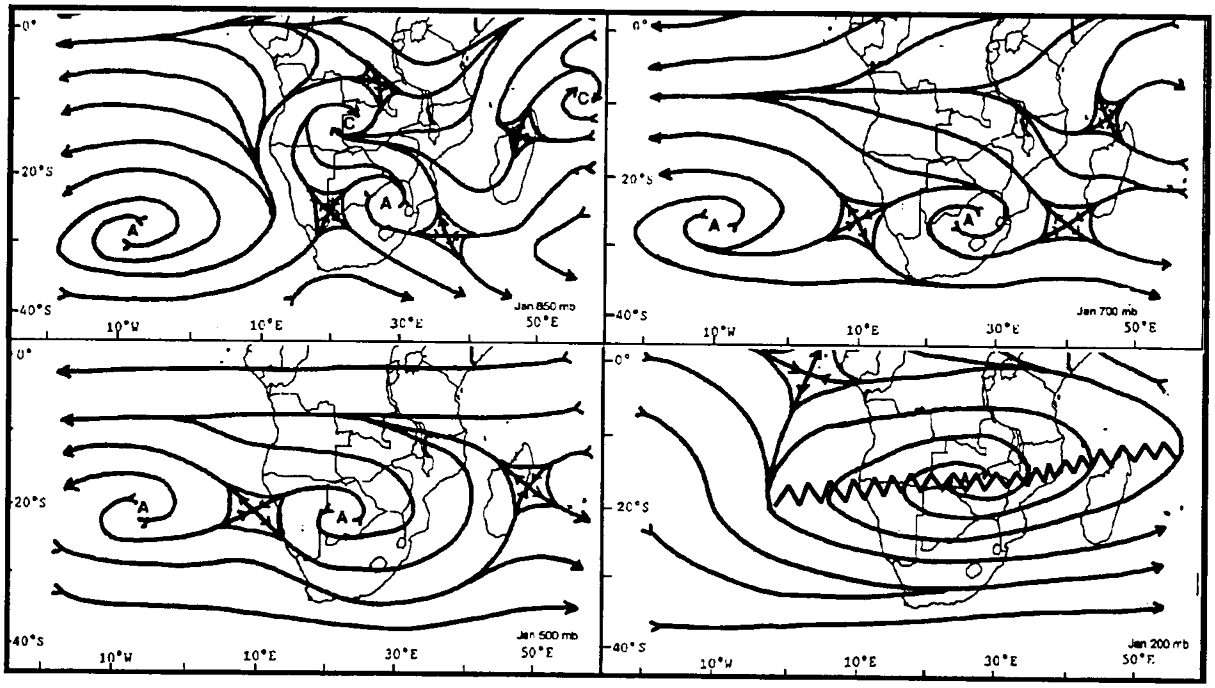



Figure 2-16. Mean January Upper-Air Flow Patterns at 850, 700, 500, and 200 mb.

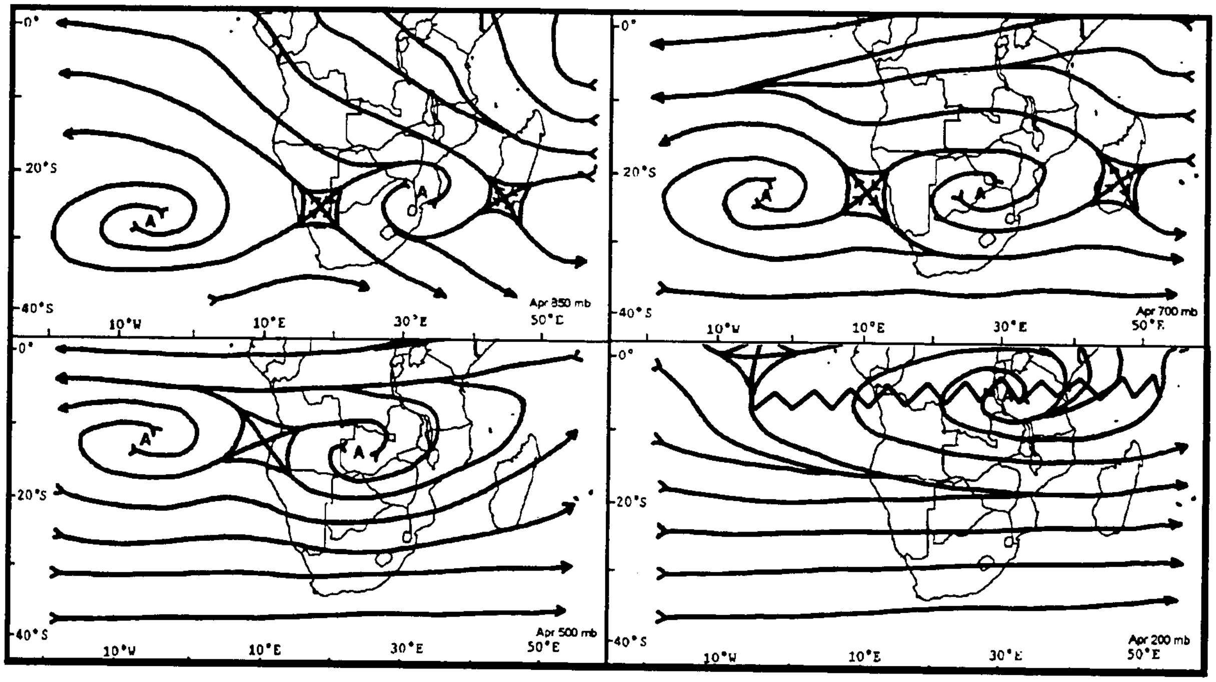



Figure 2-17. Mean April Upper-Air Flow Patterns at 850, 700, 500, and 200 mb.

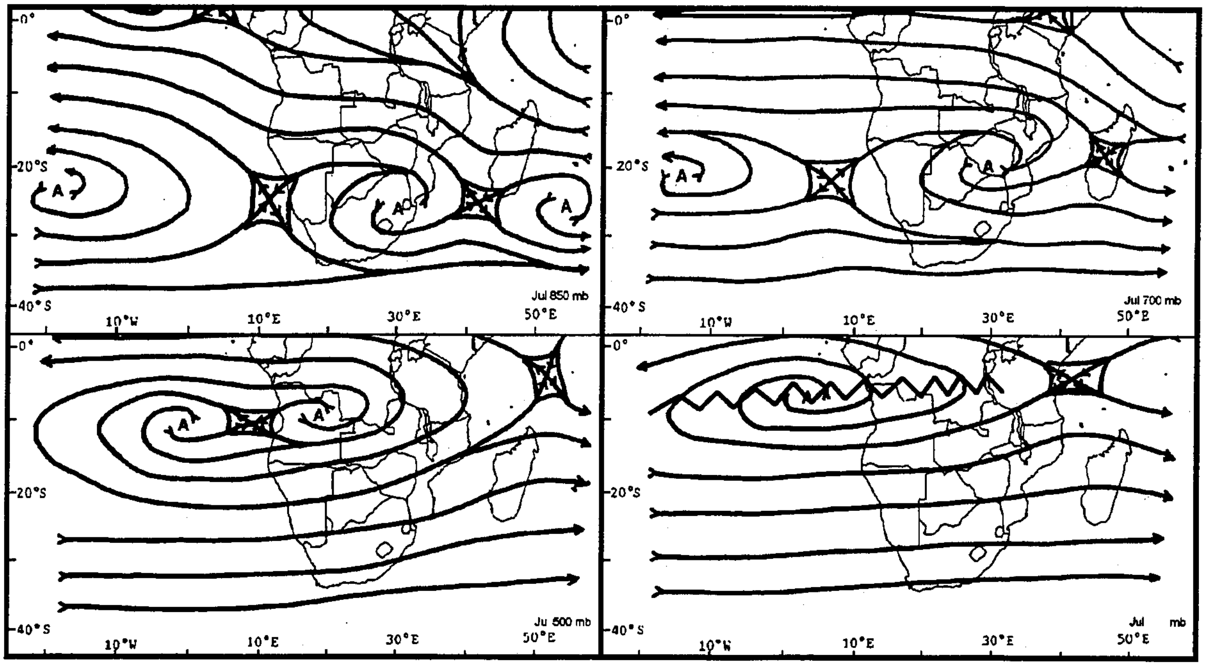



Figure 2-18. Mean July Upper-Air Flow Patterns at 850, 700, 500, and 200 mb.

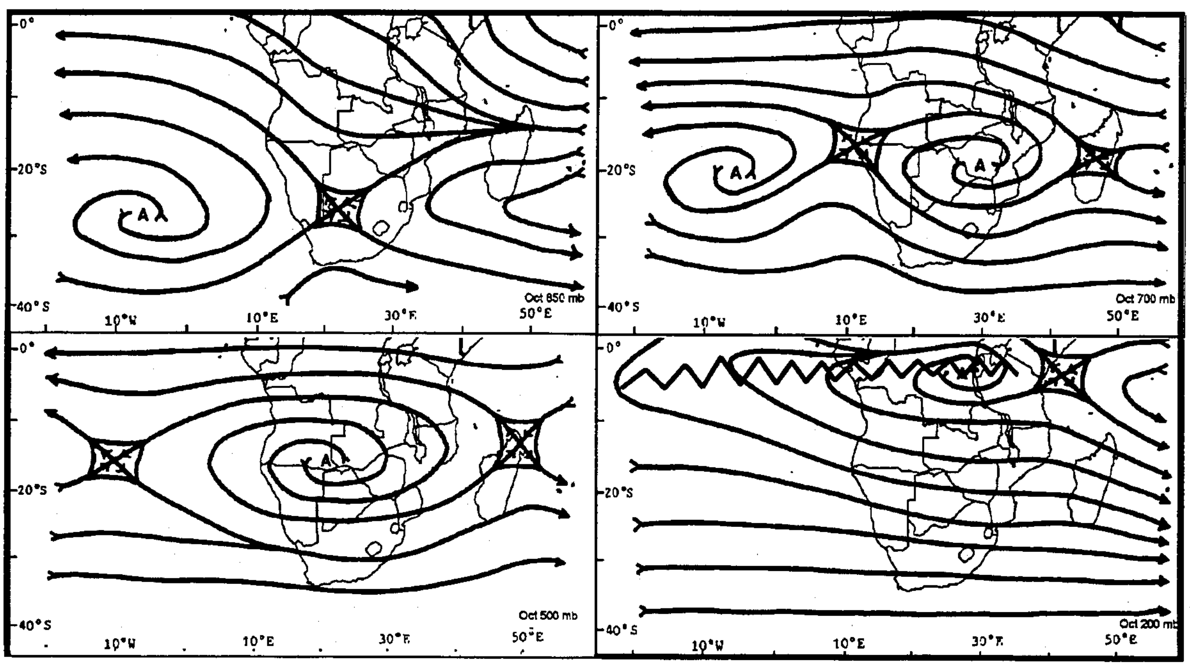



Figure 2-19. Mean October Upper-Air Flow Patterns at 850, 700, 500, and 200 mb.

## Mid-Latitude Cyclogenesis/Storm Tracks.

***South Atlantic Lows.*** These mid-latitude systems affect southern Africa year-round, but they produce only 20% of the rainfall in the region and are secondary to tropical systems. Winter is the Southern African dry season. Cyclogenesis is frequent in the western South Atlantic as warm tropical air meets polar air near the South American coast. Although these lows pass well south of Africa, their cold fronts can affect the region. The storm tracks are fairly steady from season to season and from year to year since there is no terrain modifying the flow (see Figure 2-20).

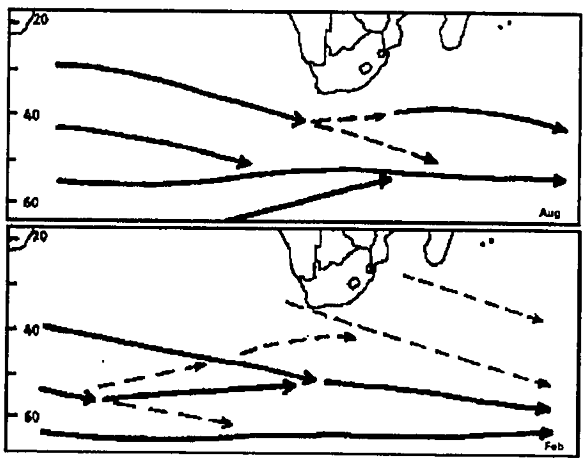



**Figure 2-20. August (Winter) and February (Summer) Storm Tracks.** Solid lines are primary tracks; dashed lines are secondary tracks.

Storms accelerate at an average of 6 knots a day as they cross the Atlantic; speeds can exceed 40 knots if the storm lies under a strong 500-mb current. North American type warm fronts seldom occur due to the strong zonal flow. Note the lack of any significant warm fronts in Figures 2-21 and 2-22.

South Atlantic Lows can intensify explosively (greater than 1 mb per hour for 24 hours), producing high winds and heavy precipitation—see the 18-23 May 1990 case shown in Figure 2-22.

Primary wintertime storm tracks are slightly north of the summer tracks. Lows most commonly travel along the Circumpolar Trough at about 55° S in the winter and at about 65° S in the summer. Lows developing off the South American coast usually move east-southeast toward this trough. Secondary lows form most frequently off the South African coast in the winter.

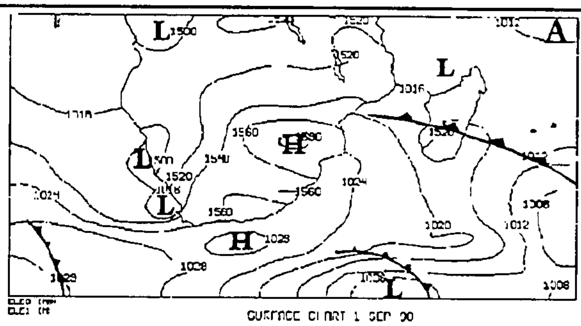
Precipitation associated with South Atlantic Lows is normally in the form of drizzle from stratiform clouds over the coasts and the higher terrain. The stratus actually comes in behind the front with the onshore southerly flow and can remain for several days. The escarpment limits the penetration of polar air primarily to the Limpopo and Zambezi River Valleys on the southeast coast, and occasionally to the Orange River Valley on the southwest coast. Thunderstorms can occur in advance of the front in the interior with stratus behind it. Tornadoes have occurred in the Johannesburg area; hail falls over the High Veldt.

***Frontal Systems.*** Although storm systems affect southern Africa year-round, there are about 10 fewer cold fronts in summer at each latitude than in winter. In the summer, the interior of southern Africa averages a frontal passage every 5 to 7 days; on the south coast, one every 2.5 days. In the winter, the interior averages a frontal passage every 4 to 6 days; on the south coast, every 2 days.

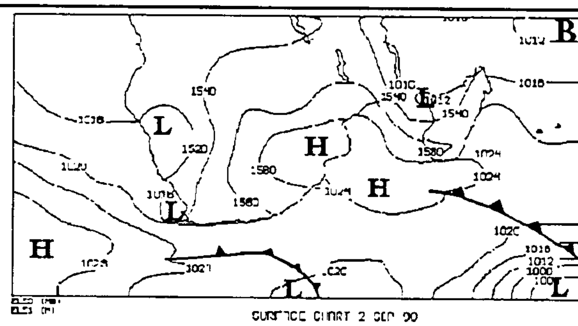
Winter fronts have penetrated northward to 10° S over central and eastern Africa, reaching Zambia and Tanzania; summer fronts rarely get north of 25° S. The west coasts of Angola and Namibia are rarely affected due to the presence of the South Atlantic High. Two to three fronts a year reach Zambia, but some years see none at all. Malawi receives rain from these fronts due its higher terrain. Cold fronts moving northeast toward Madagascar and Mozambique weaken as warm ocean currents modify the air mass. The boundary is frequently evident aloft, but not at the surface. Three to four cold fronts reach central Mozambique in a typical winter.

***Mid-to-Upper-Level Cut-Off Lows*** account for many of the flood-producing rains and snow over higher ground in southern Africa. There are 11 of these a year, on average, lasting for more than 2 days each. Peak occurrences are from March to May and from August to October; the minimum is from December to February. These cold-core systems produce convergence and vertical motion. Warm, moist tropical air is advected southward on the east side of the low, producing widespread rain on that side unless modified by topography; lows off the east coast produce onshore, upslope flow to their west. Some lows retrograde, but most are quickly pulled back into the westerly flow. Those south of the Mozambique Channel near 30° S can develop surface lows.

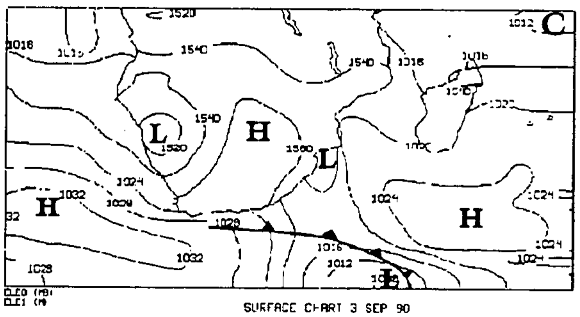
***Blocking Highs*** are rare, but they do occur between 45 and 55° S east of South America over the Scotia Sea (from 30 to 60° W) and southeast of Africa over Prince Edward and Crozet Islands (from 30 to 60° E). They form in these areas because warm sea-surface temperatures SSTs penetrate southward in the western parts of the ocean basins. They occur any time during the year except in summer. Blocking episodes normally last between 1 and 6 days, producing a split jet; in the South Atlantic, there is a once a year episode that lasts up to 10 days.



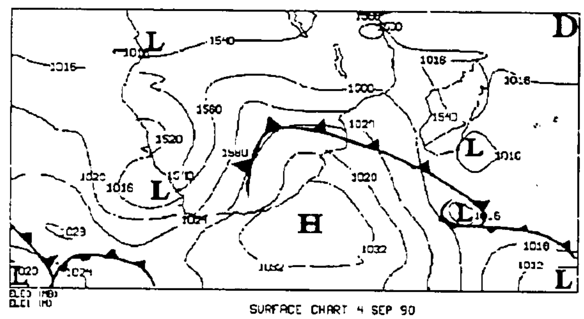

A cold front has reached central Madagascar. Another is passing to the southeast and a third approaches from the southwest. Two southern Africa coastal lows are present off the southwest coast.




The cold front over Madagascar is gone and a Mozambique Channel Low has formed with easterly flow. A high off the southeast coast prevents the second front from reaching the coast. A single coastal low is present near Capetown.

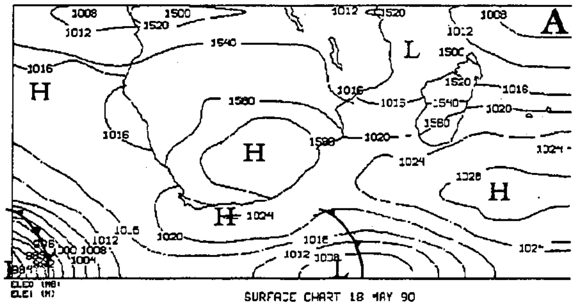



The cold front approaches South Africa from the south. The coastal low has moved over to the southeast coast.

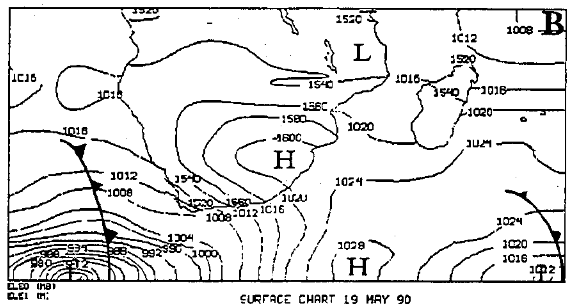



The cold front penetrates into the interior from the southeast, but it only lasts for a day. Cold air penetration occurs particularly north of Lesotho since the mountains block the normal southwesterly flow. A secondary low has formed and will move to the southeast. The coastal low on the southeast coast has filled, another has formed on the southwest coast with another front approaching from the southwest.

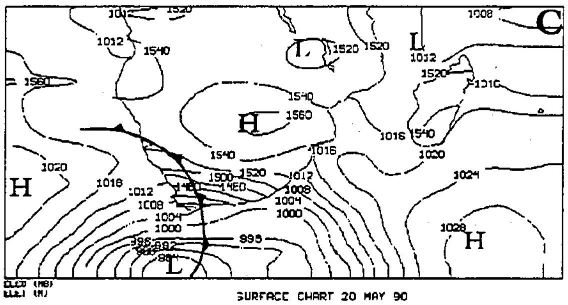
**Figure 2-21. Surface Charts, 1-4 September 1990 (1200Z). Millibars over water, 850-mb height (meters) over land.** The case shown is typical of frontal system movements throughout much of the year. Note that it is common to use the 850-mb level over southern Africa since the interior is an elevated plateau. Lows are usually well south of Africa as they pass. Cold fronts require a strong northward push to get north of 30° S.



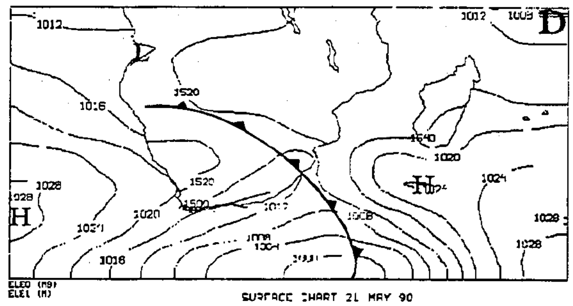

A strong system approaches from the southwest; the low is near 980 mb.



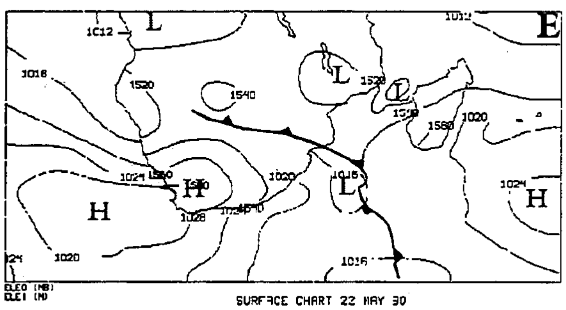

The ridge normally off the coast has been broken down and replaced by the trough. The low has deepened to under 960 mb.



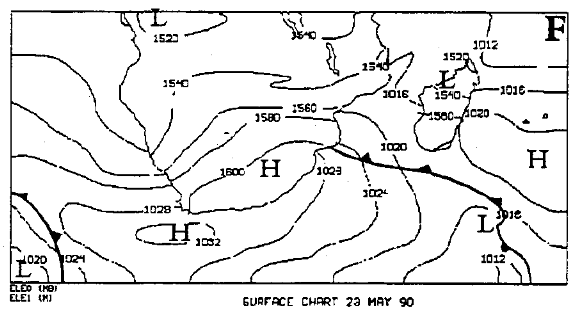

The cold front has penetrated far north along the coast.




The cold front has penetrated deep into the interior.




The cold front continues moving northeast. High pressure enters the interior from the southwest. A secondary low formed on the front and moved off to the southeast.




High pressure is established over the interior.

**Figure 2-22. Surface Charts, 18-23 May 1990 (1200Z). Millibars over water, 850-mb height (meters) over land.** The 18-23 May surface charts show an extreme case of a deep South Atlantic low breaking down the ridge over the southwest coast of South Africa. Stations around Cape Town near the southwest coast received over 107 mm of precipitation. Fifty mm fell as far north as 29° S and into the interior to about 20° E. Just under 20 mm fell up to 26° S along the desert coast and into the interior to 31° S, 22° E.

**Southern Hemisphere Polar Surges** between May and October produce fluctuations in the Somali Jet over East Africa. Frontal systems can temporarily displace the South Indian Ocean High, cutting off the normal flow pattern, while strong high pressure behind the system can produce a surge of low-level flow through the Mozambique Channel. Generally the frontal boundary does not cross the equator, but the flow "surges" can, producing sudden increases in cloudiness and precipitation.

Figure 2-23 shows a case with a strong Somali Jet and Southeast Monsoon flow. The Somali Jet is producing winds of 50 knots. The South Indian Ocean High is firmly established at 37° S, 56° E, providing the southeasterly flow into the jet from east of Madagascar.

Figure 2-24 shows the surge episode that followed shortly afterward over the region.

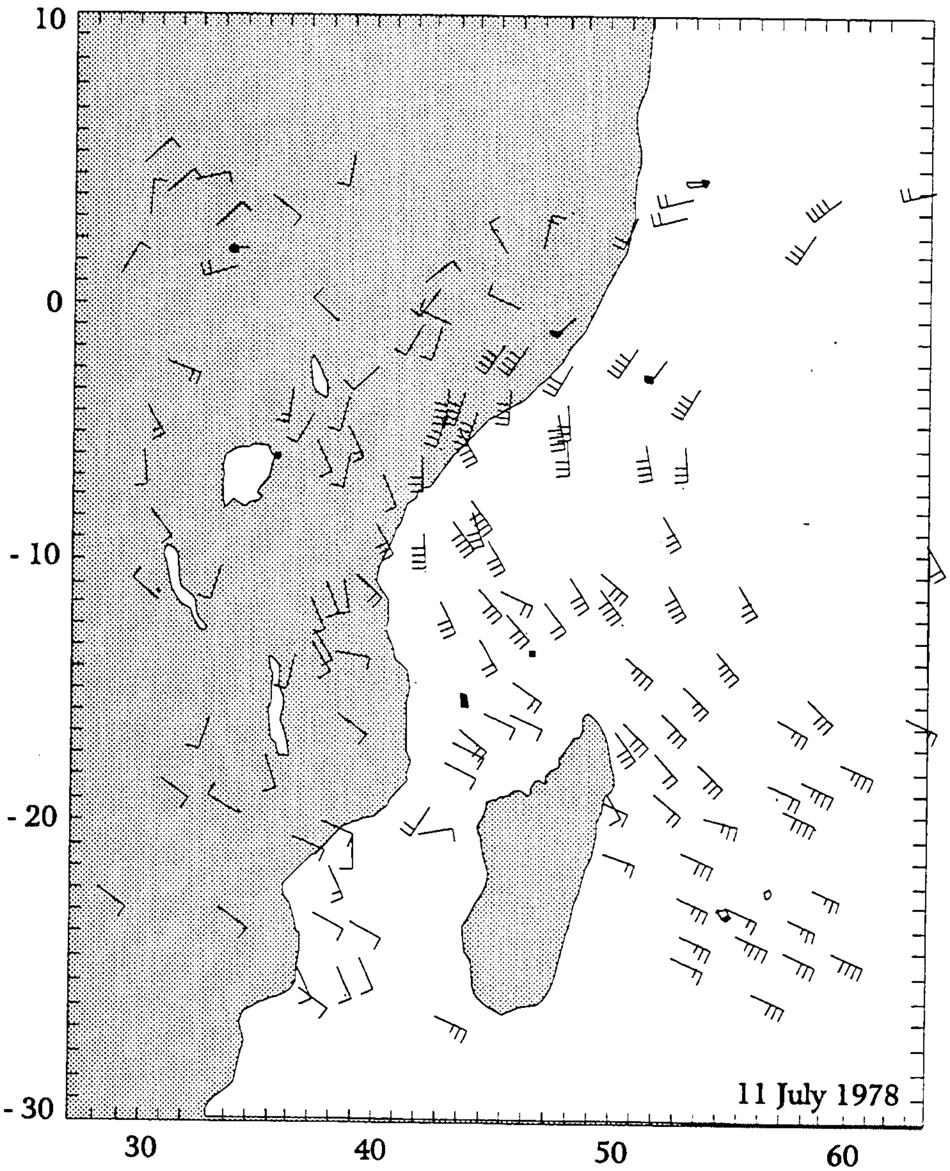
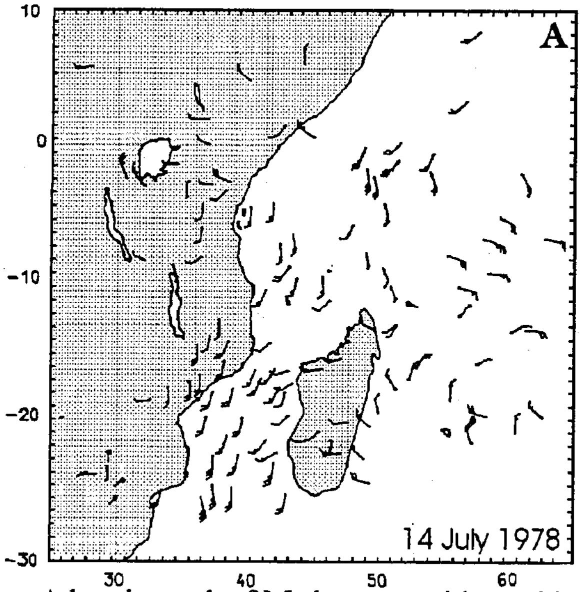
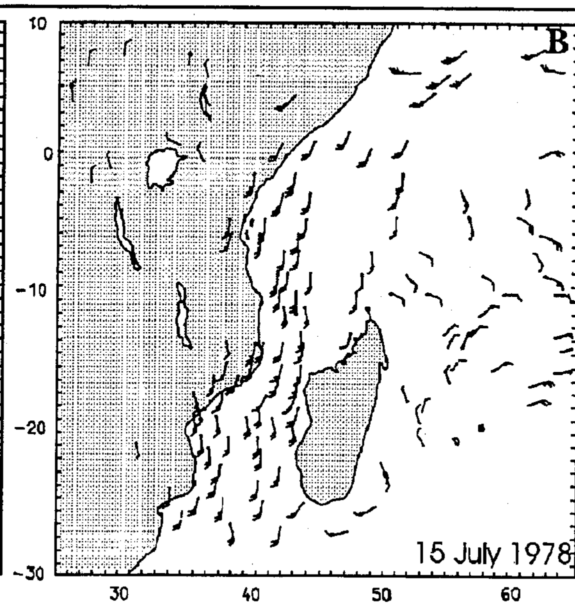


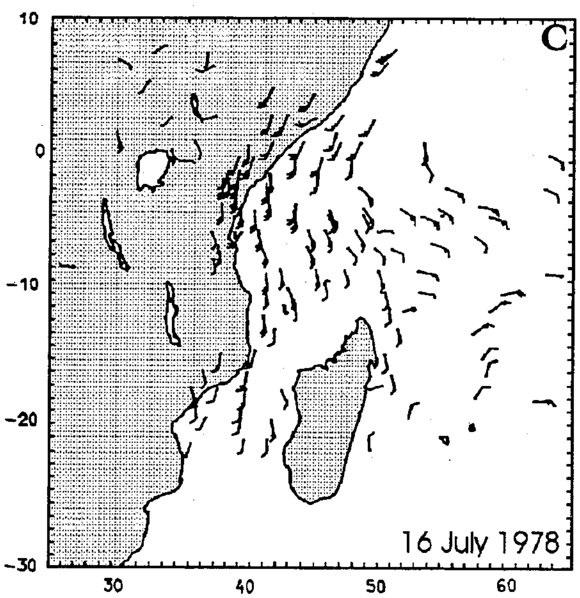

**Figure 2-23. Strong Somali Jet, 11 July 1978.** Satellite-derived wind vectors from Cadet and Desbois, 1981.



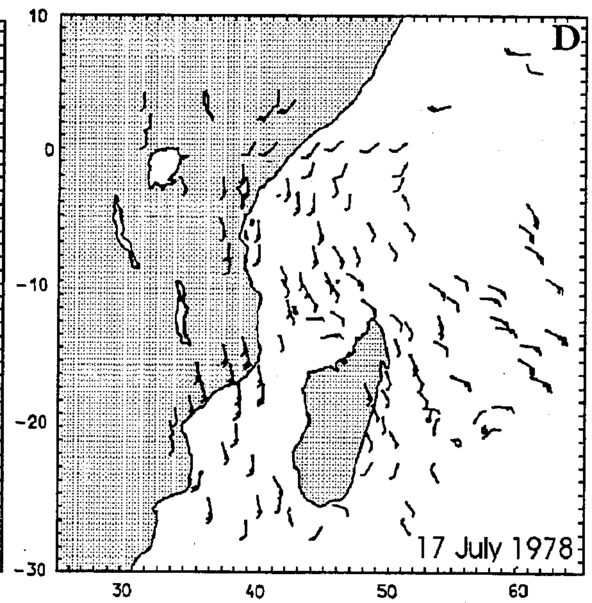

A low is south of Madagascar with a cold front extending into the channel. The South Indian Ocean High has weakened and shifted eastward. Circulation north and east of Madagascar is disorganized, cutting off normal flow into East Africa.




Flow now "surges" through the Mozambique Channel with winds of 20 to 30 knots extending along much of the coast. The flow east of Madagascar remains weak and disorganized.




Flow through the Mozambique Channel is reduced as the low and polar high move off to the southeast from Madagascar. The surge along the East African coast now extends into the northern Hemisphere.




A weak South Indian Ocean High has reestablished its position, resuming the southeasterly flow east of Madagascar. The Somali Jet is temporarily weaker than normal.

**Figure 2-24. Polar Surge, 14-17 July 1978.** Satellite-derived wind vectors from Cadet and Desbois, 1981.

**Subtropical Cyclones**, also known as "Monsoon Mid-Tropospheric Lows," develop in the South Indian Ocean when a cold pocket is cut off equatorward of the polar westerlies. They move northwestward into East Africa from July to September and westward into South Africa from September to April. They produce convection and heavy rainfall. Circulation is strongest at the mid-levels. Latent heat release through deep convection may provide enough warming to create the appearance of a tropical cyclone circulation and, given time, can actually change the low into a tropical cyclone.

Trade winds prevail at the surface away from the center. There is a subsidence inversion over the trade winds. Trade-wind flow is disrupted at the surface closer to the center. The cyclone may or may not actually develop a low at the surface.

Subtropical cyclones are self-sustaining. Convection around, but not in, the center produces a closed circulation aloft. Maximum convergence is between 400 and 600 mb, also the zone of steepest pressure gradients and strongest winds. Upward motion above this zone leads to condensation and deep convection, while descending motion below the convection is cooled by evaporation (see Figure 2-25).

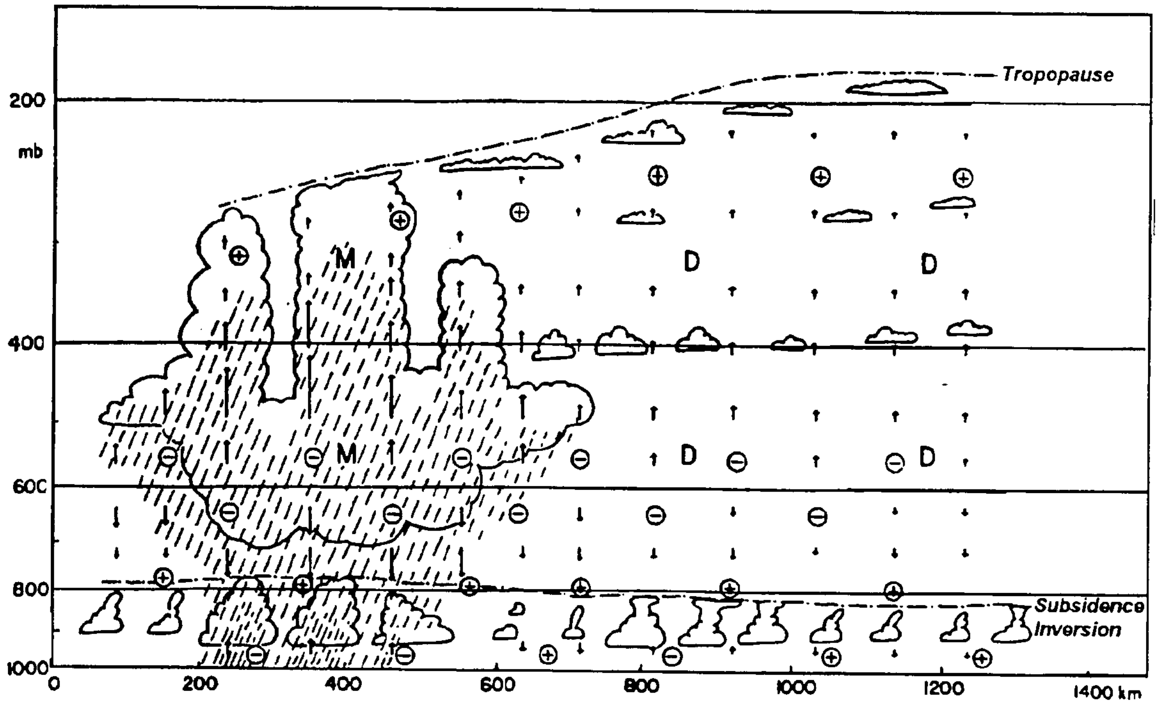



**Figure 2-25. Vertical Cross-Section of a Subtropical Cyclone (from Ramage, 1971).** Divergence is indicated by *plus* signs, convergence by *minus* signs. Regions of vertically moving air undergoing *dry* adiabatic temperature changes are denoted by "D"; regions undergoing *moist* adiabatic temperature changes are denoted by "M."

**Tropical Cyclones.** "Tropical Cyclone" is the generic southwest Indian Ocean name given to tropical storms/hurricanes with wind speeds above 33 knots. They are a major threat to Madagascar and Mozambique. Tropical cyclones can occur from November to April, with a peak in January and February. Although most develop in the Monsoon Trough east of Madagascar, a few develop or redevelop in the Mozambique Channel after crossing Madagascar. Tropical cyclones don't occur over the rest of the region; they don't form in the South Atlantic and those in the Arabian Sea don't reach the region. African Waves over West Africa can develop into tropical cyclones once they are out in the North Atlantic, but they have little effect on Africa.

Figure 2-26 shows the average number of tropical cyclones occurring per 5-degree square per year. The highest concentration is to the east of Madagascar. Most tropical cyclones approach the area from the east (usually between 10 and 20° S) and eventually recurve to the southeast. The extreme northerly position is 5° S.

An average of 10 a year form in the South Indian Ocean; most recurve to the southeast around the South Indian Ocean High before they reach Madagascar. An average of 1 to 2 a year reach the island and/or the Mozambique Channel. Most of these also recurve to the southeast. Other possibilities (but rarer) include dissipation over Madagascar, looping in the Mozambique Channel for several days (embedded in the Monsoon Trough), and moving into the interior of southern Africa (ridging extends across from the South Indian Ocean High into South Africa). In 1971, a cyclone remained in the channel for 10 days, producing extensive flooding over the Mozambique coast. Cyclones moving into southern Africa normally produce heavy rainfall, but the winds weaken rapidly.

Tropical cyclones reaching the east coast of Madagascar frequently bring winds in excess of 100 knots since they develop in the central South Indian Ocean and have plenty of time to intensify. Tropical cyclones tend to produce good weather over surrounding regions, primarily due to the upper-level outflow descending and suppressing vertical development. Zimbabwe often experiences a break in the rains and clearing when a cyclone is in the Mozambique Channel; however, the low-level northwesterly winds over Zambia move the CAB eastward, increasing precipitation in Malawi and eastern Zambia.

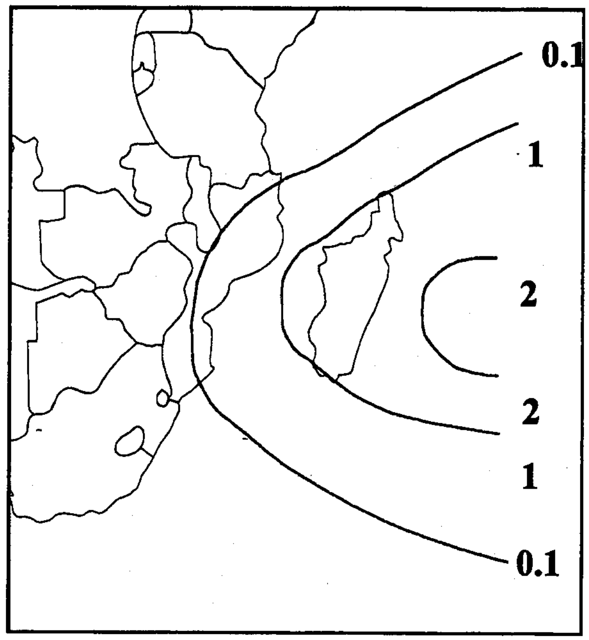



**Figure 2-26. Average Number of Tropical Cyclones (per 5 Degree Square per Year).** Most tropical cyclones approach from the east and recurve southeast.

**African (Tropical) Waves** occur in both hemispheres. In the southern hemisphere, they form over the South Indian Ocean near the NET in response to the Indian Ocean TUTT. From December to February, they form over the western portion of South Africa, over Botswana, and over Namibia. From June to September, they can also form along the Southern Equatorial Trough.

Southern hemisphere tropical waves are even less well understood than their northern hemisphere counterparts. Ramage, in the revised AWS TR 240 (*Forecasters Guide to Tropical Meteorology*, to be published in 1995), does not believe that there is an easterly wave as classically defined. Rather, he believes that these westward-moving disturbances south of the subtropical ridges are caused by upper-level troughs and lows or are the poleward extensions of extremely low-latitude vortices. Satellite imagery received at the Air Force Global Weather Central tends to support this view. In this study, as well as its companion "*Equatorial Africa—A Climatological Study,*" we will refer to such phenomena as "tropical waves."

Waves along the NET in the South Indian Ocean reach Madagascar from December to February. Some research shows that African waves occur over Botswana, Namibia, and the northern half of South Africa from December to February. Easterly flow brings in moisture through the Zambezi and Limpopo River Valleys producing a weaker version of the Mid-Tropospheric Easterly Jet (MTEJ) via funneling through the valleys. The disturbances move slowly from east to west; precipitation is concentrated on the east side of the trough. Over Botswana, they can become aligned NW-SE with the cold fronts to their southeast. Convergence can produce clouds connecting the two, spreading precipitation across South Africa.

The SET can produce tropical waves near 5° S and from 60 to 75° E from June to September. They move westward at 5 to 15 knots, occasionally reaching Kenya and Tanzania or even farther. Associated convection can produce more than 50 mm of rain.

**African (Tropical) Squall Lines.** Little is known about southern hemisphere African squall Lines except that they occur from December to February, might be linked to the CAB, and are apparently supported by a weaker version of the MTEJ. They form throughout tropical Africa, although they are best known over Sub-Saharan Africa. Studies have identified squall lines over Zambia and Zaire moving west into Angola. Winds of up to 60 knots have been observed.

Several things cause the dissipation of African squall lines and inhibit their development. They are frequently observed to dissipate completely around coastal areas; temperature inversions are believed to prevent the rising air from reaching the lifted condensation level (LCL). Dissipation also occurs if the supply of low-level moisture is cut off or if the MTEJ can't reach the surface. If thunderstorms have recently occurred in an area, a squall line can either dissipate or only produce light rain upon entering that area due to a lack of releasable energy. The air mass is fairly homogeneous after a squall line passage; subsidence can be present. Some squall lines regenerate after passing such an area.

Individual thunderstorms tend to move with the low- to mid-level synoptic flow. In the Atlantic air mass north of the CAB, thunderstorms tend to move southeast toward the CAB and its associated convergence zone. Mid-latitude squall lines, some severe, form over South Africa ahead of cold fronts penetrating from the southwest. These tend to develop in central South Africa and move to the northeast.

**Southern Africa Coastal Lows.** These lows dominate the weather along the coast and are observed year-round on a regular basis. The escarpment of southwestern Africa, acting as a barrier to low-level flow, produces these shallow, mesoscale lows that develop along the Angolan and Namibian coasts and are trapped within 90 to 200 km of the coastline. They normally propagate southeastward, then eastward, and finally northeastward around the coast of South Africa before dissipating.

Development is preceded by eastward movement of a transitory high south of the continent; this produces easterly offshore flow at the level of the escarpment over southern Africa. Dry subsiding air produces a subsidence inversion over the marine boundary layer, trapping the low-level flow. The mechanics produce lows rather than highs, which are typically followed by a frontal system approaching from the South Atlantic. The front overtakes the low; in some cases, it dissipates it.

As a low approaches a station, the pressure drops, the height of the inversion lowers, surface temperatures rise, and the dew point falls. There is a decrease in the amount of stratus. The reverse happens after passage of the low. The winds at the level of the escarpment also reverse to onshore flow after passage moves the stratus well inland. Lows move at speeds of 5-20 knots and seem to occur on a 6 day cycle. The speed of movement is normally slower along the east and west coasts and faster along the south coast. Refer to Figure 2-21 for a sequence of coastal lows occurring 1-4 September 1990.

Coastal lows are generally deeper in summer, but even then they are seldom deeper than 1,500 meters. The stratus extends farther inland in summer. On rare occasions, a summer coastal low is pulled into the NET and intensifies, moving inland along the southeast coast.

Strong, warm, offshore *berg winds* often precede coastal lows and strong, cool, onshore *buster winds* often follow them—see "Surface Winds," next section.

## Surface Winds.

***Berg Winds.*** These are are hot, dry, and occasionally strong winds that blow from the interior of southern Africa out to sea. They affect the coastal regions of southern Angola, Namibia, South Africa, and Mozambique, but occur less frequently along the southeast Africa coast, where high terrain blocks the flow. Although berg winds occur year-round, they are more common in late winter and early spring with the South African High present. They can also occur with South African coastal lows. Winds are normally perpendicular to the coast until they begin to weaken, at which time they become more parallel. Speeds normally reach 20-25 knots; occasionally, 35 knots.

High pressure over the interior plateau combined with a low-pressure system or trough passing to the south produces the necessary pressure gradient for the berg winds, which normally ends as the trough moves off and high pressure moves in. Subsidence aloft over the plateau is believed to approach the surface; the air is warmed dry adiabatically as it moves down the slopes to the coast.

Berg winds normally occur during the day, peaking before noon. The nighttime inversion usually cuts off the flow unless it is unusually strong. The flow can return the following day even if cut off at night. The most dramatic effect of the berg wind is the change in temperature. Most record highs with berg winds occur from October to April. Extreme temperatures have reached 46° C at Port Nolloth in northwestern South Africa. Changes can be rapid; as much as much as 17 degrees C in 2-3 hours has been observed. Visibility normally improves, except on the west coast where dust often accompanies berg winds.

***Buster Winds.*** "Buster wind" is a term used in Africa and Australia for the sudden shift of wind behind a trough that can reach gale-force strength and cause sharp temperature drops. Buster winds spring up suddenly, with average speeds of 20-30 knots and gusts to 50 knots. They bring in low cloud and fog quickly. Busters are usually short-lived; wind speeds drop back to normal within an hour.

***Cape Southeaster.*** The Cape Southeaster is a cool summer wind that brings fair weather to the southern portions of South Africa. This southerly to southeasterly wind normally brings subsidence and good weather for several days except along the windward sides of mountains, where stratus forms. The advance of a new high from the southwest generally marks the beginning of a southeaster; duration is dependent on speed of movement and size of the high. A low-pressure area is also needed over the African interior (the normal condition in summer) for the formation of a Cape Southeaster. Winds are generally between 15 and 30 knots, but strong pressure gradients can result in speeds up to 50 knots. The area normally affected by Cape Southeasters extends from the Cape of Good Hope to Port Elizabeth; locations farther east are more likely to get low cloud and rain. Winds quickly diminish when a trough approaches the area.

***Black Southeaster.*** This is the term used for the southerly winds behind a cold front that bring nimbostratus, light rain, and turbulence along the mountains and escarpment of the southern and southeastern coasts. The poor weather usually extends from the escarpment out over the coasts and can last several days. The strongest events occur with a mid- to upper-level cut-off low over South Africa supplying cold air aloft.

***Land/sea Breeze.*** Differential surface heating generates this diurnal phenomena along most of Africa's coastline. The marine boundary layer rarely extends above 915 meters AGL or 30 km inland unless modified by synoptic flow. Two types of land/sea breezes are found: "common" and "frontal."

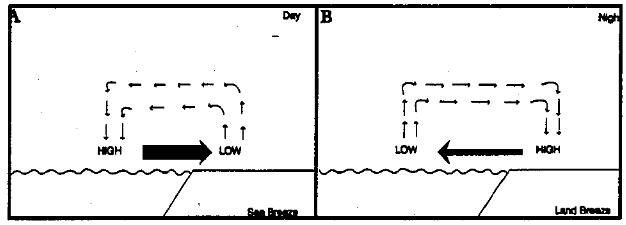



**Figure 2-27. The "Common" Sea (A) and Land (B) Breezes.** Thick arrows depict the gradient flow.

• *"Common" land/sea breezes* affect all coastal areas of Central and Southern Africa. Figure 2-27 illustrates the "common" land/sea breeze circulation under calm conditions with no topographic influences and a uniform coastline. Onshore (A) and offshore (B) flow intensifies in proportion to daily heat exchanges between land and water. Common land/sea breezes normally reverse at dawn and dusk.

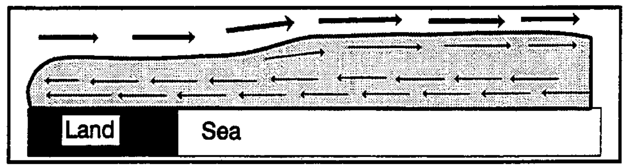



**Figure 2-28. A Fully Formed "Frontal" Sea Breeze.** Arrows depict wind flow; the shaded area is the marine air mass.

• *"Frontal" land/sea breezes* are sharp discontinuities between land and sea air masses. Strong offshore gradient flow produces the frontal land breeze. It delays the onset of the sea breeze by 1 to 4 hours as gradient flow prevents the sea breeze boundary layer or "front" from moving ashore. When it does move onshore, it sometimes sustains 20-knot winds for 15-45 minutes. Figure 2-28 shows a typical frontal sea breeze.

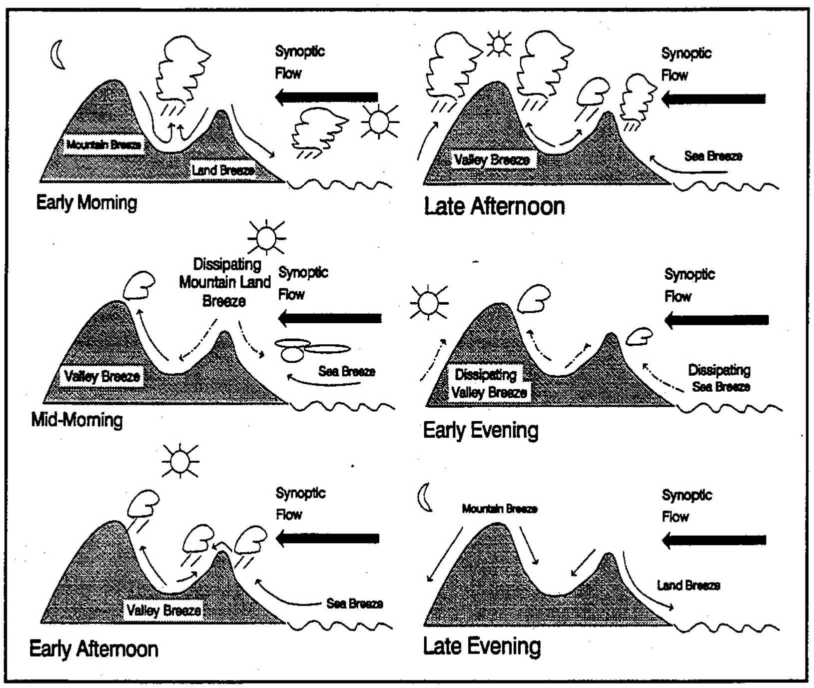



**Figure 2-29. Land/Sea Breeze With Onshore Gradient Flow.**

High terrain near the coastline modifies the land/sea breeze in several ways. Orographic lifting produces sea-breeze stratiform/cumuliform cloudiness and deflects surface winds, while the mesoscale mountain circulation accelerates the land breeze over water. Elevated coastal topography produces steep nighttime temperature gradients.

Figure 2-29 shows the land/sea breeze circulation with onshore gradient winds and coastal topography. Onshore gradient flow accelerates orographic lifting by day and produces localized convergence over open water during the early morning hours. This land/sea breeze convection pattern develops in locations such as the eastern coast of Madagascar.

Coastal configuration also has an effect on land/sea breezes. Coastlines perpendicular to landward synoptic flow maximize sea breeze penetration, while coastlines parallel to the flow minimize them.

The sea breeze has a dominant affect on the coasts of Angola and Namibia. It is modified by the South Atlantic High to a south-southwesterly direction by mid-afternoon; average speeds are from 10 to 25 knots, but they can reach 40 knots. The sea breeze can extend up to 60 km inland, terrain permitting. The winds normally back over time; the land breeze goes through easterly to northerly by morning; the initial sea breeze backs around to the west by noon. The land breeze wind speeds are light since they oppose the synoptic flow.

Southern Africa's coast is affected by the mid-latitude westerlies in such a way that the influence of the land/sea breeze is reduced. Sea breezes are more of a factor during the summer, while cold air over the interior makes land breezes stronger in winter. Land/sea breezes develop regularly along the east coast, producing northeasterly winds at 10 to 25 knots during the day and northwesterly winds at 5 knots at night. Much of South Africa's coast is narrow, limiting the distance inland a sea breeze can penetrate; the escarpments appear to be the boundary. Sea breezes penetrate farther into river valleys than elsewhere.

The eastern coast of Southern Africa can experience land/sea breezes year-round, except when overriden by stronger winds from disturbances such as tropical cyclones or polar surges. The sea breeze is strongest in the summer, with speeds of between 10 and 25 knots. Land breezes are generally westerly; sea breezes, east-northeasterly.

The sea breeze is very significant over Madagascar. It supplements the easterly trades on the east coast; speeds can reach 35 knots, especially near mountains. The west coast is more sheltered, allowing the sea breeze to extend up to 90 km inland; speeds are usually 10 to 20 knots. The land breeze is normally light on both coasts.

**Land/Lake Breezes.** Several localized variations of a land/sea breeze circulation are caused by differential heating over large lakes. This circulation occurs in the absence of strong synoptic flow, and has a vertical depth ranging from 200 to 500 meters AGL. In late afternoons, a cloud-free lake is surrounded by a ring of convection some 20 to 40 km inland from shore. By early morning, the flow reverses and localized convergence occurs over open water. Figure 2-30 shows a land/lake circulation and cloud pattern with no synoptic flow.

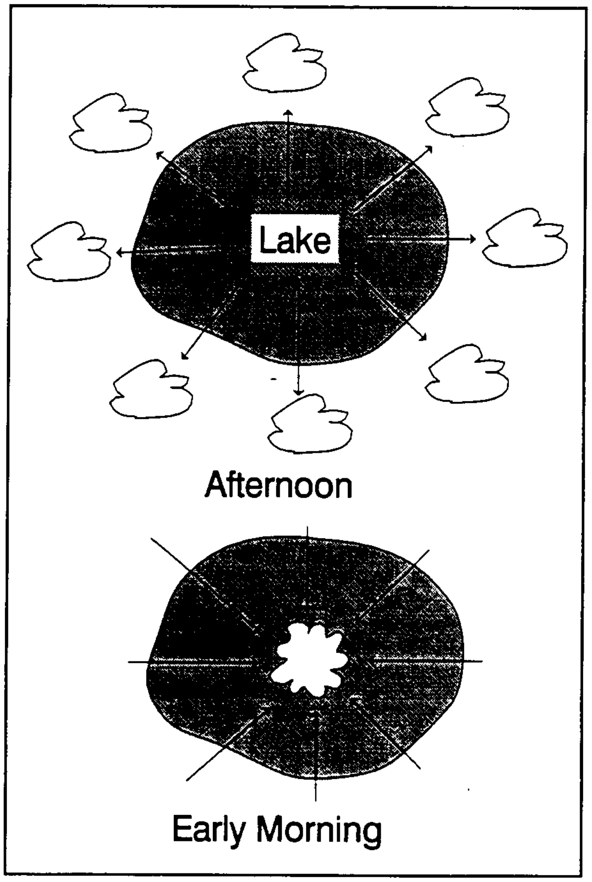



**Figure 2-30. Idealized Land/Lake Breezes with Cloud Pattern.**

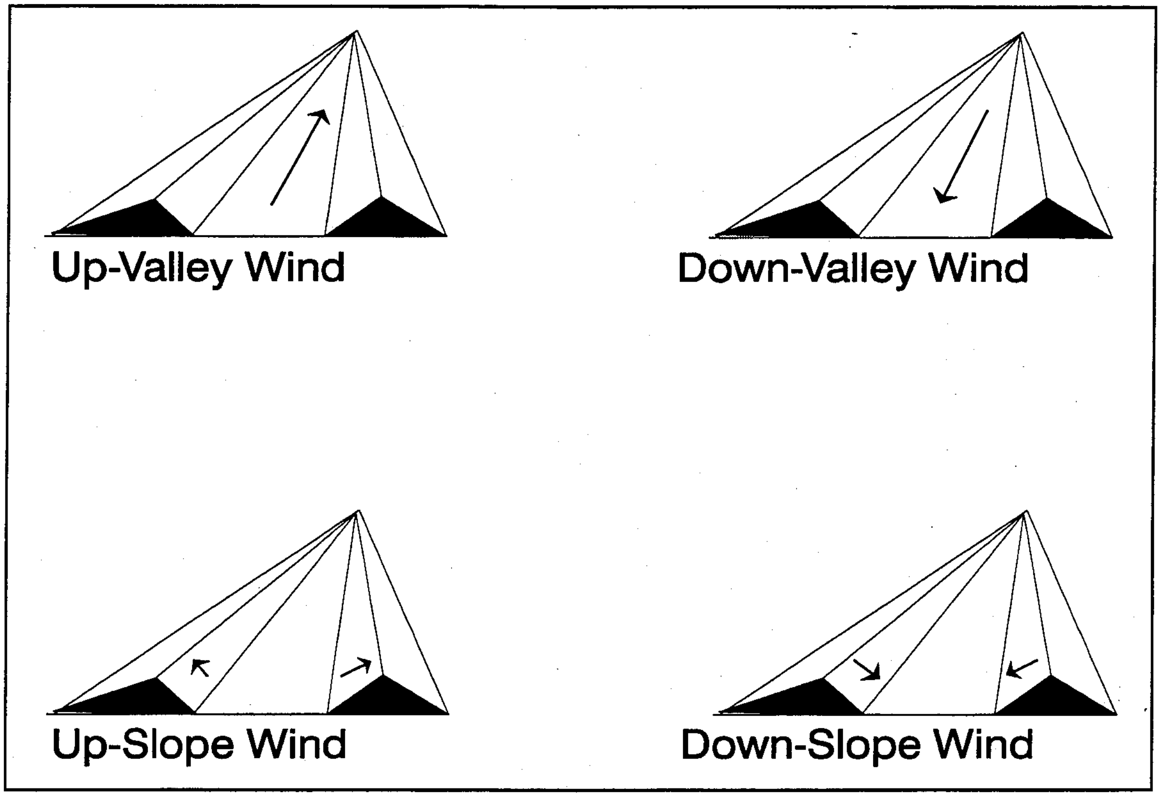



**Figure 2-31. Mountain-Valley and Slope Winds. (from Whiteman, 1990).**

***Mountain-Valley and Slope Winds*** develop under fair skies with light and variable synoptic flow. The two types of terrain-induced winds are shown in Figure 2-31. Mountain-valley winds tend to be stronger than slope winds and can override their influence.

• *Mountain-Valley winds* are produced in response to a pressure gradient between a mountain valley and a plain outside the valley. Air within the valley heats and cools faster than air over the plain. Daytime, up-valley winds are strongest, averaging 10-15 knots between 200 and 400 meters AGL. Nighttime down-valley winds average only 3-7 knots at the same level. Peak winds occur at the valley exit. Deep valleys develop more nocturnal cloud cover than shallow valleys because nocturnal airflow convergence is stronger. The mesoscale mountain-valley circulation, which has a maximum vertical extent of 2,000 meters AGL, is determined by valley depth and width, the strength of prevailing winds in the mid-troposphere (stronger winds producing a shallower circulation), and the breadth of microscale slope winds. The return flow aloft is much weaker and broader since it isn't confined to a narrow valley.

• *Slope Winds* develop along the surface boundary layer (0-150 meters AGL) of mountains and large hills. Mean daytime up-slope wind speeds are 6-8 knots; mean nighttime down-slope wind speeds are 4-6 knots. Steep slopes can produce higher speeds, but these speeds are found at elevations no higher than 40 meters AGL. Down-slope winds are strongest during the season with the greatest *cooling,* while up-slope winds are strongest during the season of greatest *heating*. Up-slope winds are strongest on slopes facing the sun. Winds from a larger mountain can disrupt the winds of a smaller mountain. In some locations, cold air can be dammed up on a plateau or in a narrow valley. When sufficient air accumulates, it can spill over in an "air avalanche" of strong winds.

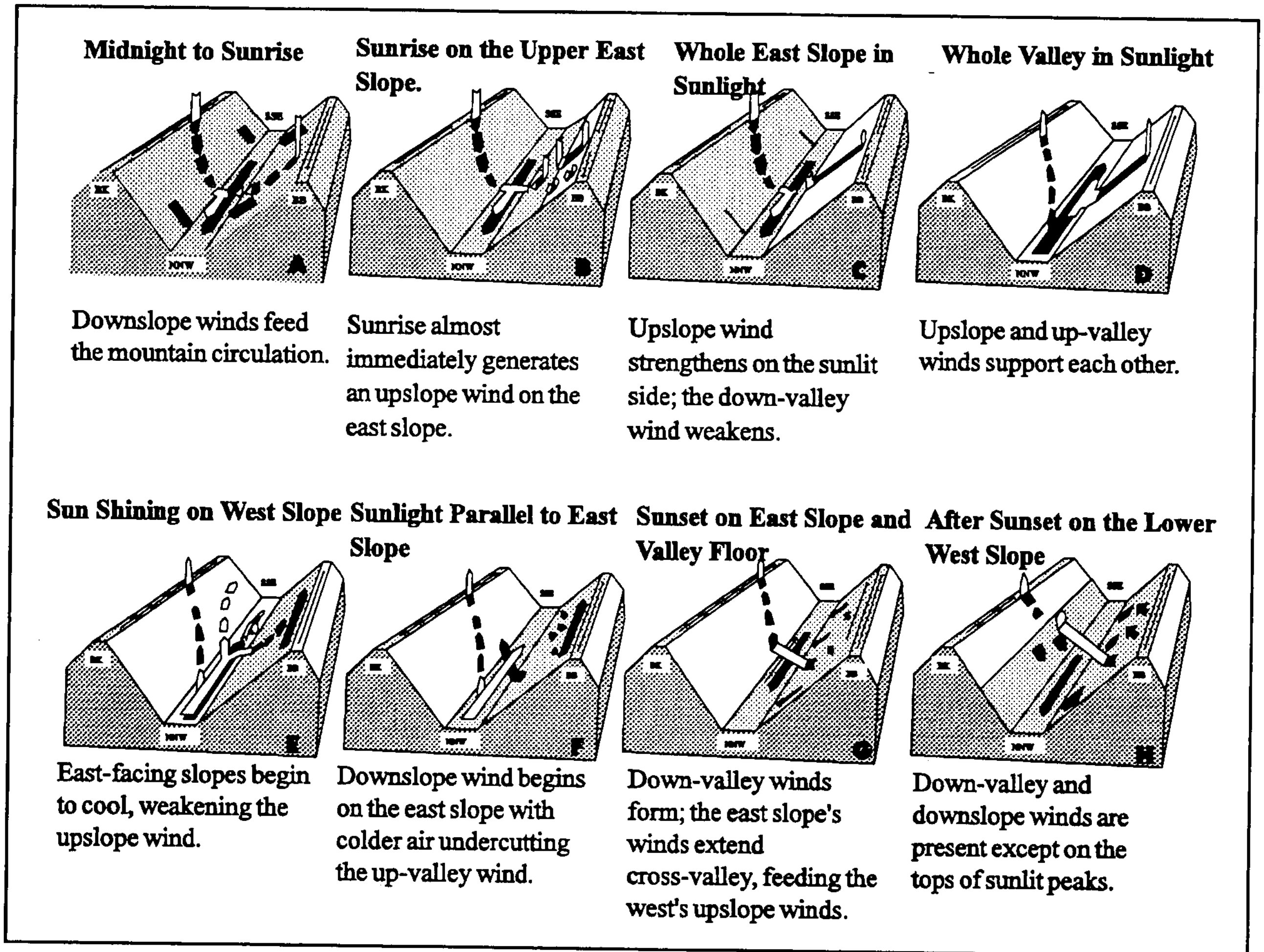



**Figure 2-32. Diurnal Variation of Slope and Valley Winds** (from Barry, 1981).

Figure 2-32 shows the life cycle of typical mountain-valley and slope wind circulations. Both valley and slope winds are shown in relation to two ridges (BK and BB) oriented NNW-SSE. The dark arrows show the flow near the ground; the light arrows show movement of the air above the ground. Mountain inversions develop when cold air builds up along wide valley floors. Cold air descends from slopes above the valley at 8-12 knots, but loses momentum when it spreads out over the valley floor. Wind speeds average only 2-4 knots by the time the down-slope flow from both slopes converge. The cold air replaces warm, moist valley air at the surface and produces a thin smoke and fog layer near the base of the inversion. First light initiates up-slope winds by warming the cold air trapped on the valley floor. Warming of the entire boundary layer begins near the 150-meter level AGL. The southeast side of the Drakensburg escarpment in eastern South Africa presents a special case. The escarpment edge drops from 3,000 meters to a plateau at about 900 meters. The Plateau is cut by valleys from 240 to 540 meters deep. Some valleys parallel the slope, while others are at right angles to it. Figure 2-33 shows the nighttime air flow over the region. The dark arrows show the flow due to the escarpment and the white arrows show the flow due to the valleys. The daytime winds are reversed.

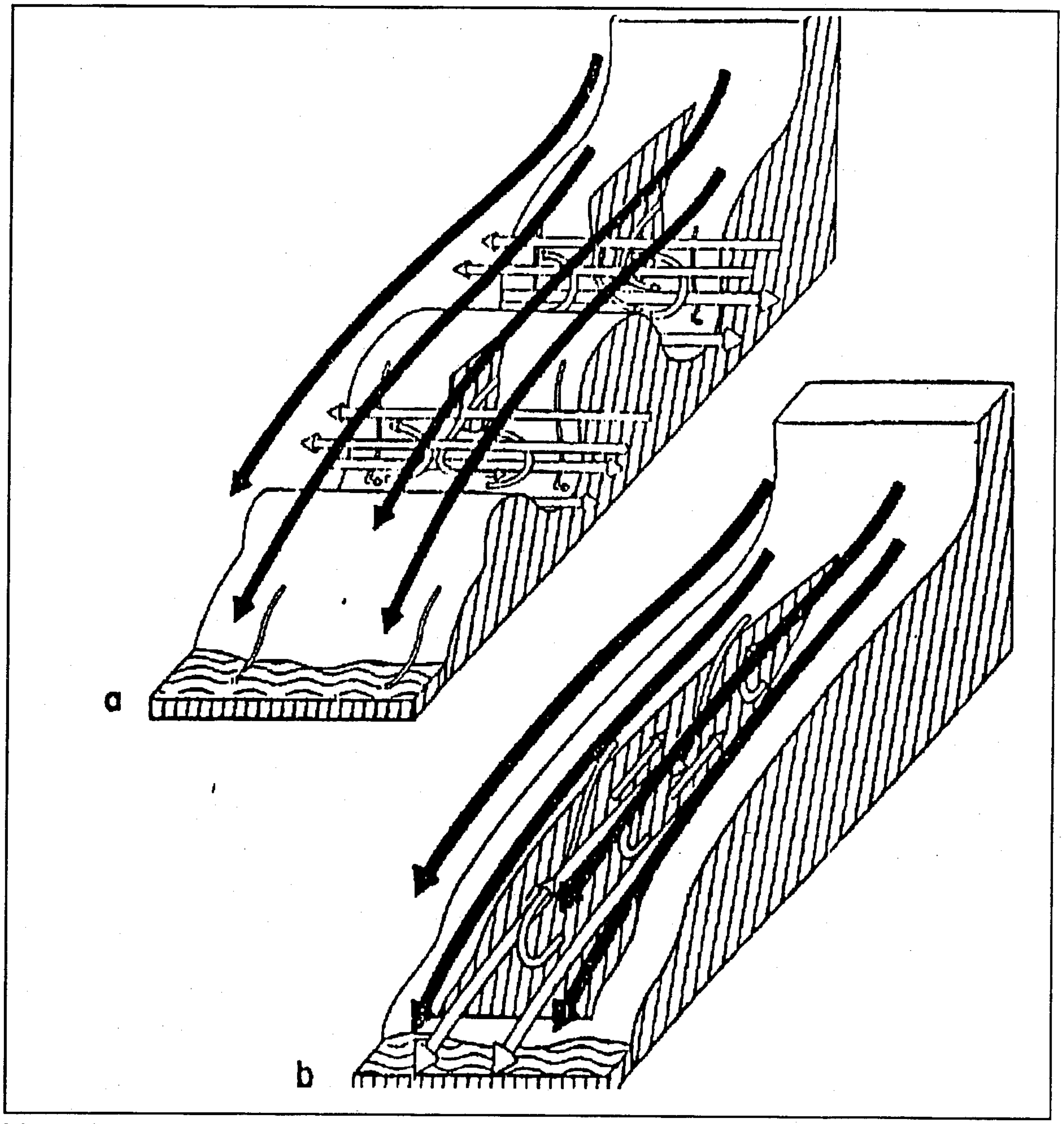



**Figure 2-33. Nighttime Airflow over the Drakensberg Foothills in Winter for Valleys at Right Angles (a), and Parallel to the Slope (b) .**

*Mountain Waves* develop when air at lower levels is forced up over the windward side of the ridge. Criteria for mountain wave formation include sustained winds of 15-25 knots, winds increasing with height, and flow oriented within 30 degrees of perpendicular to the ridge.

Wavelength amplitude is dependent on wind speed and lapse rate above the ridge. Light winds follow the contour of the ridge with little displacement above and rapid damping beyond. Stronger winds displace air above the stable inversion layer; upward displacement of air can reach the tropopause.

Downstream, the wave propagates for an average distance of 50 times the ridge height. Rotor clouds form when there is a core of strong wind moving over the ridge, but the elevation of the core does not exceed 1.5 times the ridge height. Rotor clouds produce the strongest turbulence. The clouds may not always be visible in dry regions. Figure 2-34 is an illustration of a fully developed lee-wave system.

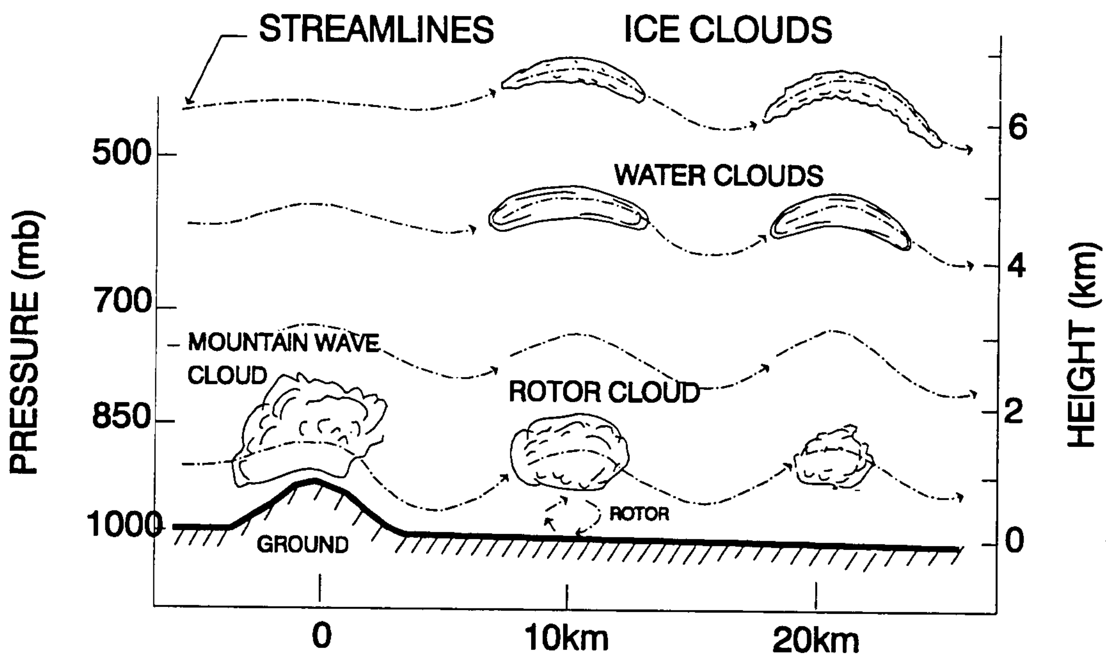



**Figure 2-34. Fully developed Lee-Wave System** (from Wallace and Hobbs, 1977).

**Duststorms/Sandstorms.** Given the right conditions, duststorms are dominant features in and near the deserts of the region. Duststorms carry suspended particles over long distances, often reducing visibility to less than 10 meters. Season of occurrence, wind direction, amount of particulate matter, and duration vary by locality. Large-scale duststorms often persist for 1 or 2 days before a frontal passage (such as that of an Atlas Low), or with a synoptic-scale squall line. Mesoscale squall lines may reduce visibility to less than 1,000 meters for several minutes to an hour. Sandstorms differ from duststorms only in the size of the suspended particles. Sand, being heavier, is seldom raised to more than 1-2 meters above the ground; the particles settle quickly.

Strong pressure gradients produced by mid-latitude surges and by tropical disturbances generate the winds needed to produce synoptic-scale duststorms. Most large-scale dust clouds move toward the west and the equator.

Winds of 15-20 knots are sufficient to lift dust and sand. The mean threshold value is 17 knots, but speeds as low as 10-12 knots can produce duststorms. A pressure gradient of 6 mb/10 degrees of latitude produces widespread duststorms 50% of the time. Only a 4 mb/10 degrees of latitude surface pressure gradient is necessary to generate dust-laden surface winds.

Dust devils resemble miniature tornadoes, but their wind speeds are generally between 10 and 25 knots. They can, however, get strong enough to flatten huts. They form in clear skies and are set off by intense summer daytime heating and local turbulence. Diameters range from 3 to 90 meters, averaging around 6 meters. Most reach 75 meters high; dust has been observed at 900 meters. Dust devils move at about 10 knots and last for 1 to 5 minutes. Visibilities are near zero in the vortex. They are common across the desert regions of the southern African interior.

The origin and nature of duststorms depend upon: 1) *general synoptic conditions*, (2) *local surface conditions*, (3) *seasonal considerations*, and (4) *diurnal considerations.*

***(1) General Synoptic Conditions.***

- *Active cold fronts.* Duststorms can develop with frontal passages. Strong fronts increase the size of the area affected considerably and can produce a "wall of sand."

- *Convective activity.* Convective downdrafts commonly reach speeds needed to produce duststorms and sandstorms. Visibilities can be greatly reduced within minutes. Duststorms created by convective downdrafts are frequently called "Haboobs." These are common in the western interior of southern Africa. The Namib Desert of Namibia is particularly noted for sandstorms. Railway lines have been blocked by drifts of sand reaching 4 meters high.

- *Stagnant Surface High Pressure.* The South African High normally strengthens over the subtropics during extended fair-weather periods. This high sometimes produces severe and widespread duststorm activity that is most difficult to forecast. Although such situations are easy to recognize, precise locations (timing and areal extent) are difficult to infer with so little data available. Stagnant air aloft provides little ventilation to remove the dust.

***(2) Local Surface Conditions.*** Soil type and condition control the amount of particulate matter that can be raised into the atmosphere. Dry sand or silt, for example, is easily lifted by 10-15 knot winds. Haze is a persistent feature of the sandy deserts. The fine dust, salt, or silt can be suspended for weeks and travel hundreds, even thousands, of kilometers from the source. Vehicles crossing the sand break through the crust easily; even light winds can raise dust.

*(3) Seasonal Considerations.*

- *Winter.* Large areas of dust/haze develop when there is subsidence aloft and a lack of turbulent mixing. Most duststorms develop along frontal boundaries. Synoptic-scale winds of only 10-15 knots can lower visibility to below 5,000 meters over large areas for up to 12 hours.

- *Summer.* Convection produces most duststorms, but late-spring frontal systems also produce them. Duststorms are more frequent in summer than in winter. Local visibilities can fall below 5,000 meters in areas where the soil is dry.

*(4) Diurnal Considerations.*

- *Daytime.* The lowest visibilities occur around 0900L, shortly after the inversion breaks and turbulent surface mixing raises the dust; distant tree tops can be visible, but their bases are obscured by the dust/haze. Daytime heating produces turbulent mixing in the lowest layers. Hot, dry winds transport dust aloft to the base of the large-scale subsidence inversion. Persistent dryness allows dust to reach 3,000 meters MSL, where it can remain suspended for days or weeks.

- *Nighttime.* Cooler surface temperatures create stable conditions in the surface layer. Turbulent mixing is minimized; visibilities improve during the night and are best between 2000 and 0600L as the temperature inversion produces light surface winds. Dust settles beneath the inversion layer throughout the night; visibilities improve to 6-10 km.

**Guti and Chiperoni**. The "Guti" of Zimbabwe and Zambia and the "Chiperoni" of Malawi are intervals of extensive low-level cloudiness, fog, and drizzle that occur year-round and last for periods of 1 to 5 days. They originate when transitory highs advect cooler or cold air from South Africa into the Mozambique Channel. The air becomes cool and moist before moving into the Limpopo, Zambezi, and Shire River valleys. As air moves inland, it rises along the highlands and reaches southeastern Zimbabwe and southern Malawi as a cold, nearly saturated airmass. Adjoining districts of Zambia are also affected, but less often.

These invasions are normally associated with moderate-to-strong southeasterly winds that can gust up to 45 knots. Widespread stratus with bases between 500 and 1,000 feet sometimes extends as far west as Bulawayo in Zimbabwe and the Muchinga Escarpment in Zambia (800 kilometers inland). Precipitation is generally drizzle, especially on windward slopes where clouds are at their lowest and thickest and orographic rain is frequent. Temperatures usually lower with the onset and remain steady even at night.

During the rainy season, these disturbances are often preceded by squall-line thunderstorms that develop 150 kilometers ahead of the boundary of moist, southeasterly flow. The stratus is usually thicker and more persistent than in the dry season.

During the dry season, the tops of the stratus are generally lower. The Guti/Chiperoni tends to develop in the morning with lifting or complete clearing by afternoon.

**Wet-Bulb Globe Temperature (WBGT) Heat Stress Index.** The WBGT heat stress index provides values that can be used to calculate the effects of heat stress on individuals. WBGT is computed using the formula:

$$WBGT = 0.7WB + 0.2BG + 0.1\,DB$$

where: WB = wet-bulb temperature
BG = Vernon black-globe temperature
DB = dry-bulb temperature

A complete description of the WBGT heat stress index and the apparatus used to derive it is given in Appendix A of TB MED 507, *Prevention, Treatment and Control of Heat Injury*, July 1980, published by the Army, Navy, and Air Force. The physical activity guidelines shown in Figure 2-35 are based on those used by the three services. Note that the wear of body armor or NBC gear adds 6° C to the WBGT; activity should be adjusted accordingly.

| WBGT (°C) | Water Requirement | Work/Rest Interval | Activity Restrictions |
|---|---|---|---|
| 32-up | 2 quarts/hour | 20/40 | Suspend all strenuous exercise. |
| 31-32 | 1.5 - 2 quarts/hour | 30/30 | No heavy exercise for troops with less than 12 weeks hot weather training. |
| 29-31 | 1 - 1.5 quarts/hour | 45/15 | No heavy exercise for unacclimated troops, no classes in sun, continuous moderate training 3rd week. |
| 28-29 | .5 - 1 quart/hour | 50/10 | Use discretion in planning heavy exercise for unacclimated personnel. |
| 24-28 | .5 quart/hour | 50/10 | Caution: Extremely intense exertion may cause heat injury. |

**Figure 2-35. WBGT Heat Stress Index Activity Guidelines.**

Figure 2-36 gives mean daily high WBGTs for January, April, July, and October. For more information, see USAFETAC/TN-90/005, *Wet Bulb Globe Temperature, A Global Climatology*.

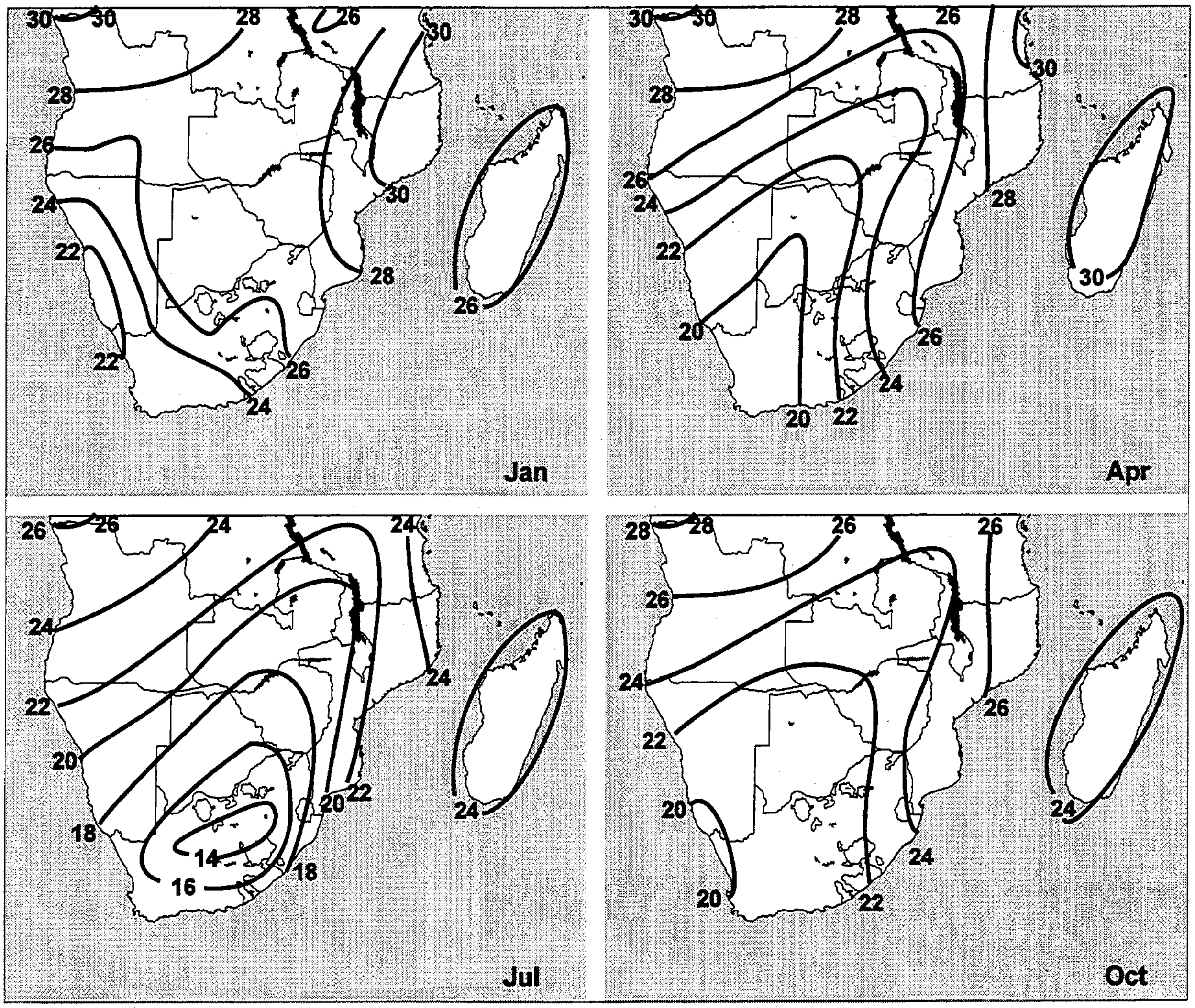
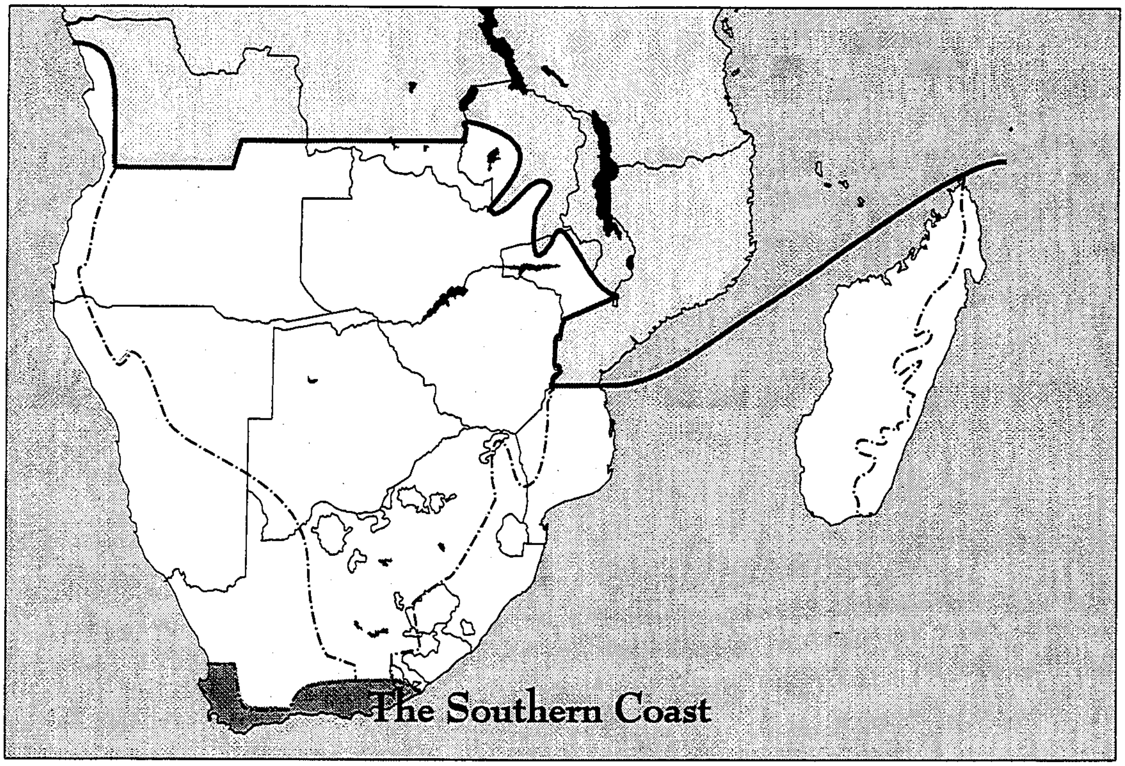



**Figure 2-36. Average Daily High WBGT (° C).**

# Chapter 3

## THE SOUTHERN COAST

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for the extreme southern coast of Southern Africa, as shown below.



## SOUTHERN COAST GEOGRAPHY

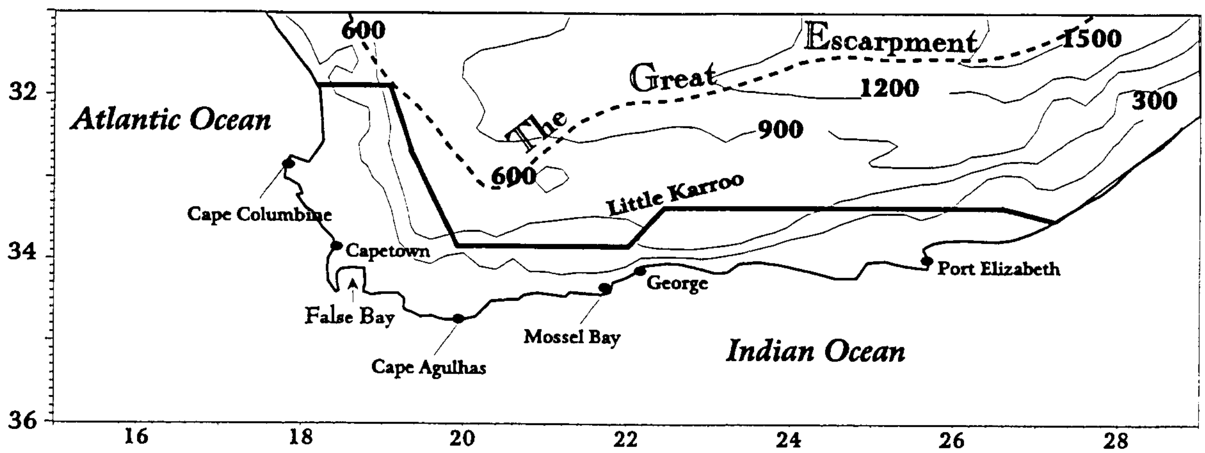



**Figure 3-1. The Southern Coast of Southern Africa.**

**Boundaries.** This is the only region in Southern Africa that has a temperate climate and four seasons (winter, spring, summer, and fall). On the west coast, the northern boundary is the line at which annual precipitation drops below 250 mm ; Across the rest of the region, it is where the climate changes to a November-March wet season. The boundary starts at 32° S, 18° E, and moves east to 19°. It then moves southeast along an upland area to 34° S, 20° E. Finally, it proceeds east along the base of the uplands until it reaches the Indian Ocean at about 34° S.

**Major Terrain Features.** Africa's Southern Coast contains both coastal plains and mountains. Most of these mountains, although too small and isolated to be shown in Figure 3-1, rise to at least 600 meters. To the north of the area lie more mountain ranges and the Great Escarpment, which prevents all but the strongest frontal systems from penetrating farther north into the continent. In the east, the strip of coastal plain is very narrow, ranging from 10 to 45 km. Near George, the coastal plain begins to widen, reaching about 75 km near Cape Agulhas. It narrows again near False Bay, then widens to about 80 km along the northwestern part of the region.

**Rivers and Vegetation.** Although there are no significant rivers or waterways in this region, some small, short rivers flow irregularly toward the sea. Most of the vegetation is shrub-like. The only forests are found in the the extreme south between Cape Agulhas and Mossel Bay.

## MAJOR CLIMATIC CONTROLS OF THE SOUTHERN COAST

**Influences of the Thermal Low.** A thermal low is centered over the northern border of South Africa during summer, with a trough extending to the southern coast. The Indian Ocean High and the South Atlantic High are weaker than normal and farthest south; a weak ridge of high pressure extends between them along the coast. The flow from the relatively warm Indian Ocean has a long over-water trajectory around the two highs' northern peripheries; it reaches South Africa as moist, unstable air that produces cloudiness and rain over eastern areas. Flow from the South Atlantic High brings in moisture that produces clouds along coastal mountains.

**Influences of High-Pressure Cells.** In winter, the thermal low is replaced by the South African High, which extends between the Indian Ocean and South Atlantic highs. These two high-pressure cells are at their maximum intensities and displaced slightly northward of their mean summer positions, but the Indian Ocean High is centered much closer to the Republic of South Africa. The steep pressure gradient that has remained south of the continent in the summer moves northward in harmony with the northward movement of the two oceanic highs. The associated storm tracks also move north, bringing the Southern Coast its greatest cloud cover and highest precipitation.

**Air Masses.** In summer, modified-maritime tropical air is brought in by "southeasters." The result is good weather in the west and southwest, but the southeast flow often brings orographic rain and low clouds to the extreme south. During prolonged southeasters, clouds form on the mountain tops.

Unstable modified-maritime polar air masses are generally cool, arriving in the rear of a low behind the cold front. Winds are westerly or southwesterly; instability is limited to the lowest 500 meters. The weather is showery, especially about midday and in the evening. Polar air masses are associated with the advance of a cold high in the rear of a low. They bring the coldest weather; because of their great instability, they also bring thick clouds, heavy rain, hail, and sometimes snow. They occur about five times a year and are not confined to any one season.

## SPECIAL CLIMATIC FEATURES OF THE SOUTHERN COAST

**The Agulhas Current.** This is a warm current that flows south through the Mozambique Channel. Lines of cumulus and cumulonimbus often form over this current, which is discussed in detail later in the chapter.

**The Benguela Current.** This cold current originates in coastal upwelling of relatively cold water; it flows northward along the entire length of the west coast and is often the source of fog and stratus in the northwestern part of the region.

**Berg Winds** are warm winds that originate from the interior and blow to the coast. They are responsible for remarkable rises in temperature along coastal areas. They occur mainly late in winter and early spring. See Chapter 2 for a detailed discussion.

**General Weather.** A trough extends southward from the northern interior into the region. Mid-level flow is weaker than that of winter. The continental high pressure that sometimes occurs over the Plateau subregion (Chapter 5) brings calm, dry weather. Extended periods of high pressure bring high temperatures. Subsidence causes decreased cloud formation.

Fronts are common on the Southern Coast. Although a closed surface low sometimes accompanies fronts, closed upper-air lows normally do not. Fronts occur about every 2-8 days, most frequently early in the season. Clouds and precipitation resulting from convergence and onshore moist flow accompany the fronts, which sometimes develop into cut-off lows over southwestern South Africa. Flow on the east side of such systems brings warm and moist tropical air into the area. Orographic lifting and convergence produce extensive cloudiness and precipitation. Cut-off lows affect the region about 50% of the time in December, but only about 5% of the time in January; frequency increases to 20% in February. Cut-off lows last for 2-3 days.

Strong easterly waves affect the Southern Coast about 10 days a month. They produce cloudiness and precipitation over the eastern half of the area.

Warm and dry clear weather is associated with deep ridging off the southwest coast. Showers associated with the trough aloft east of this ridging may occur over extreme eastern areas. This pattern is most common in February.

A combination of an intense high close to the coast and a deep depression over the interior sometimes leads to a strong easterly wind (known as the "Black Southeaster") that occasionally brings in rainy weather. As the forward area of the high approaches, it brings low cumulus and showers, followed later by nimbostratus and drizzle that may last for several days. This event is often preceded by a southwest wind backing to the south and east; hence the name.

In western areas, a slight variation of the Black Southeaster is called the "Cape Southeaster." This strong wind, normally accompanied by good weather, may blow for several days with little interruption. It, too, is caused by low pressure over the interior and high pressure seaward. One notable feature is the suddenness with which it can end when a depression approaches the coast; the wind usually backs at the same time. See Chapter 2 for details.

**Sky Cover.** Although the season-to-season changes are slight, ceilings and cloud development are at their yearly minimum due to the lower frequency of frontal systems that affect the area.

The primary cloud type is cumulus, which develops from 2,000 to 4,000 feet. Tops can exceed 10,000 feet. Stratus may be present in the morning due to moist flow from the ocean or from thick fog lifting; bases are near 1,000 feet. The stratus is not very thick; it lifts and dissipates through the morning.

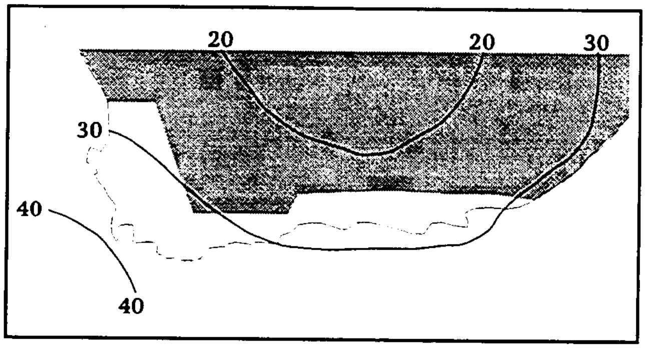



**Figure 3-2. January Percent Frequencies of Ceilings.**

Although summer ceiling frequencies (Figure 3-2) are slightly less than in winter, occurrences of low ceilings (Figure 3-3) are about the same or, in some cases, slightly more because of Black Southeasters, which can cause mountains and hills to become shrouded in heavy clouds as moisture-laden air rises and condenses. Ceilings can fall below 500 feet with these events. Figure 3-3 shows that most low ceilings occur during morning and evening.

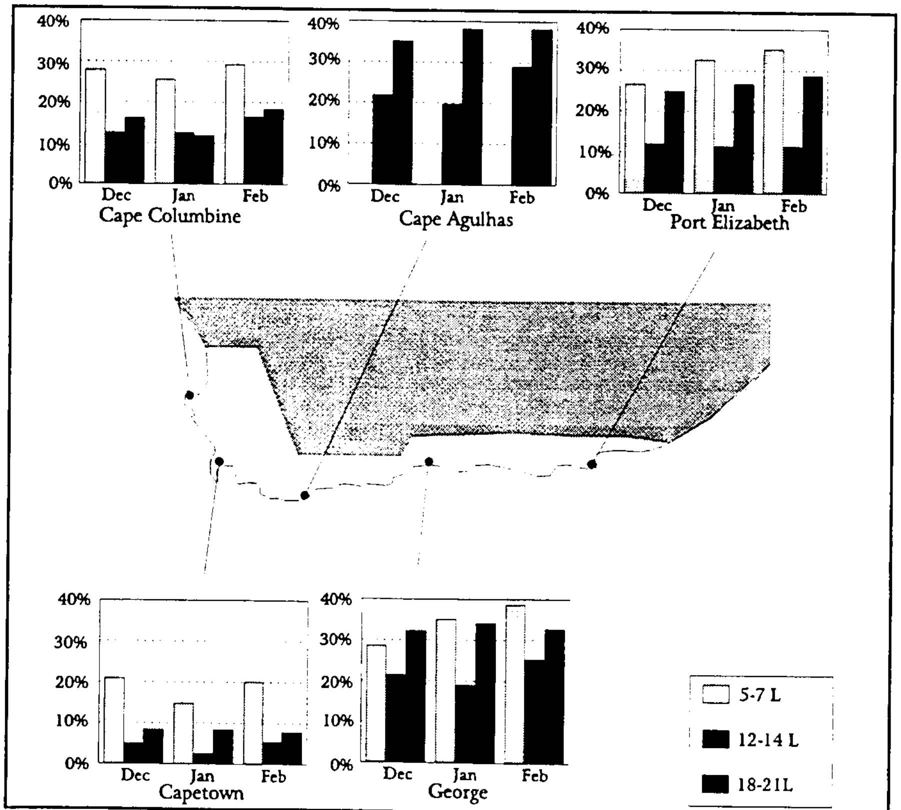



**Figure 3-3. Summer Percent Frequencies of of Ceilings Below 3,000 Feet.** Cape Agulhas observations for 05-07L are not available.

**Visibility.** Summer visibilities are very good. The primary restriction to vision is fog, which is most common during the morning. The foggiest time of the year is late summer to early winter; this is reflected in Figure 3-4, which shows frequencies increasing through the season.

Cape Columbine has, by far, the most fog of any station because of the interaction of the cool Benguela Current with the warm air over land. Morning fog forms at Cape Columbine on about 1 day in 5. The average number of hours that visibility is less than 2,400 meters ranges from 50 hours a month in December to 115 hours in February. Visibility improves south of Cape Columbine as the Benguela Current narrows and fog decreases.

During a light southeaster, thin mist or haze often covers False Bay, making the mountains on one side of the bay invisible from the other.

In eastern areas, fog is not nearly as common as in the west, but it occurs occasionally in the vicinity of Port Elizabeth. Fog is most likely when late summer light easterly flow brings warm, moist air over land; this fog occurs at night and seldom persists beyond mid-morning.

The drizzle that accompanies Black Southeasters can lower visibilities to less than 1,600 meters.

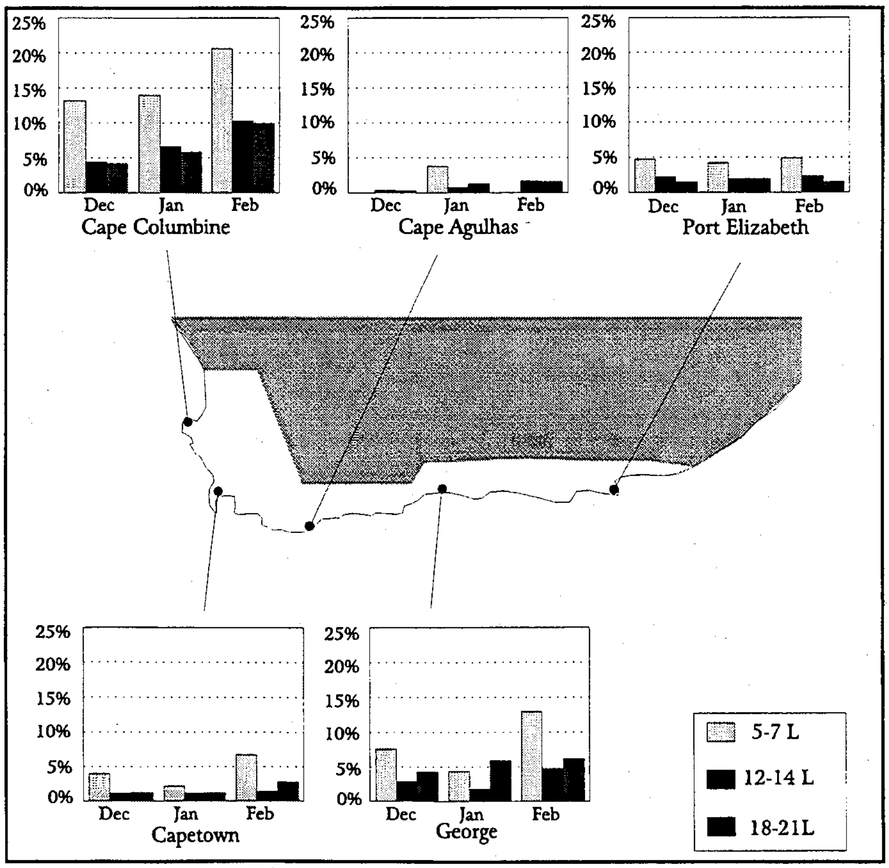



**Figure 3-4. Summer Percent Frequencies of Visibilities Below 4,800 meters.** Cape Agulhas observations for 05-07L are not available.

**Winds.** The coastline and the mountains between the sea and the escarpment modify the direction of surface winds, causing considerable variability. On the immediate coast, the surface winds conform to the trend of the coastline. Summer is the windiest time of the year due to the strong pressure gradient between the semipermanent South Atlantic High and low pressure in the interior.

Inland, winds are lighter than on immediate coasts. In some of the less exposed places, the frequency of calms in the mornings may be as high as 50%. Although prevailing directions become more westerly, they are likely to be modified by topography. A comparison of 00Z and 12Z wind roses for the stations shown in Figure 3-5 shows little diurnal variation. The land/sea breeze circulation is noticeable in eastern areas, but it is not significant in the west. Even in the east, winds vary by less than 45 degrees except when they are light. At night, winds generally blow from the west or southwest; occasionally, from the northwest. Winds begin to back and strengthen about 0800L when westerlies become southwesterly and southwesterlies become southerly. Veering begins at about 1800L, but the land is not cold enough to cause an appreciable land breeze. Even though directions do not change greatly in western areas, speeds are considerably stronger during the day. Mountain/valley circulation occurs in interior areas. Berg winds occasionally develop.

Winds aloft are west to northwesterly with mean speeds of about 30 knots at 700 mb and about 50 knots at 300 mb.

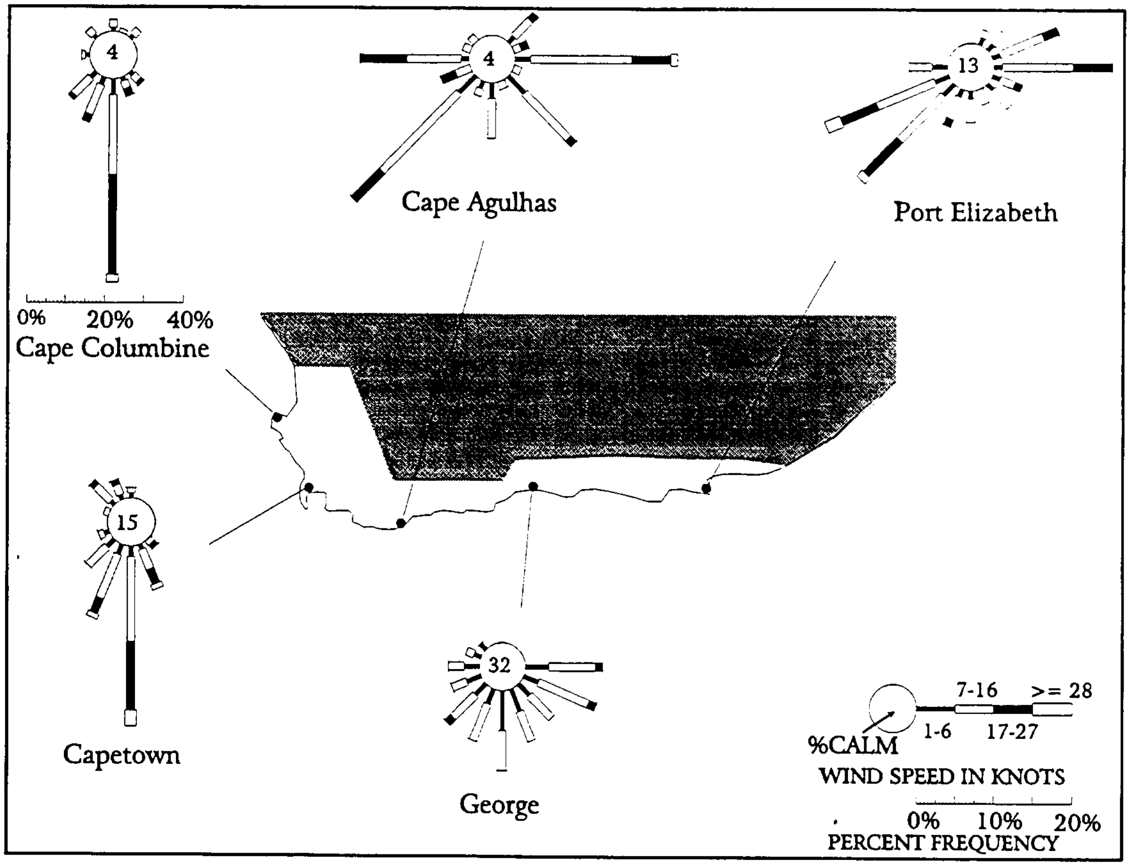



**Figure 3-5. January Surface Wind Roses.**

**Precipitation.** Summers are rainy only along the immediate coast around George, where amounts approach their yearly maximum because of favorable exposure to onshore winds. The dependence on wind exposure is evident in Figure 3-6, which shows that there are many small areas of <10 mm and 50 mm. Except in the southern coastal mountains, most of the rain falls inland.

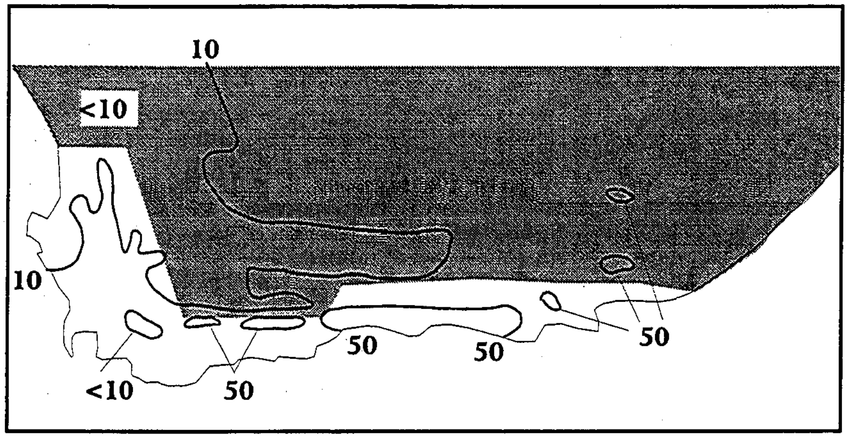



**Figure 3-6. January Mean Precipitation (mm).**

Most precipitation falls from brief afternoon or evening showers. Precipitation amounts are less than 10% of the annual total for western areas but closer to 25% of the annual total for all other areas. This fits well with the number of days with rain shown in Figure 3-7.

In the mountains, heavy precipitation often falls from orographically induced showers associated with southeast winds. This rainfall swells mountain streams and occasionally causes flash-flooding along some of the larger rivers.

**Thunderstorms** are most likely inland where orographic lift aids in their development. As shown in Figure 3-7, thunderstorms are practically nonexistent in western areas; they only occur on 1-2 days a month in the east. Thunderstorms are generally not severe, but some inland areas have received very small hail. Thunderstorm tops are generally below 40,000 feet.

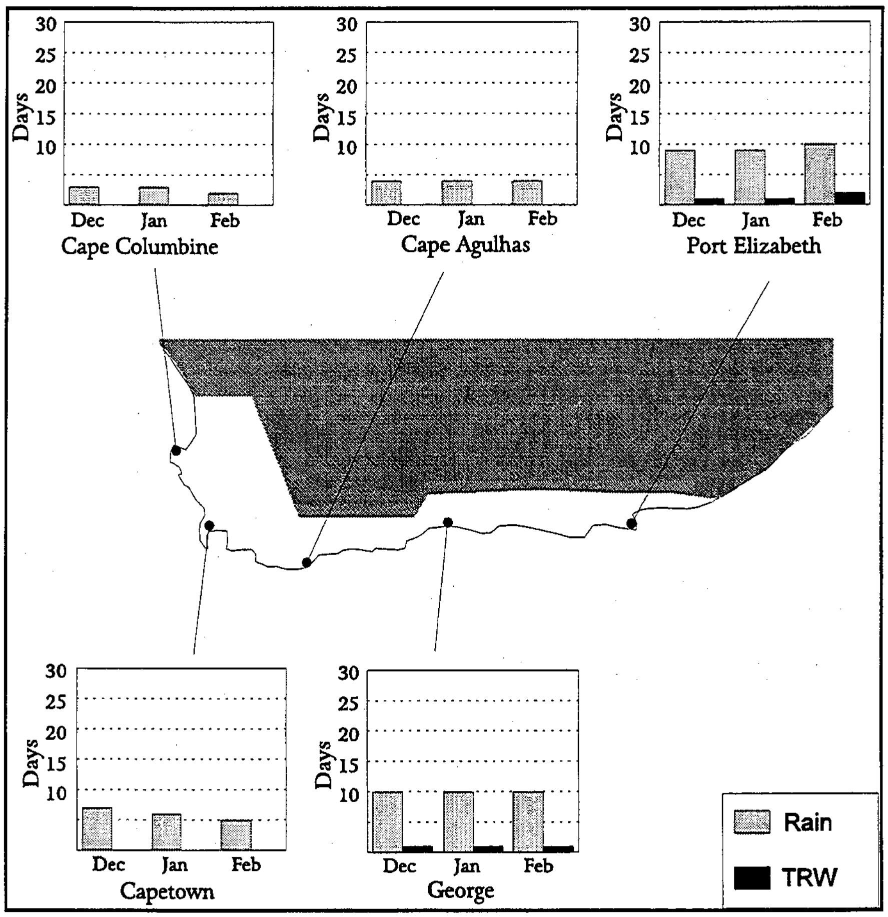



**Figure 3-7. Summer Mean Monthly Rain and Thunderstorm Days.**

**Temperature.** Temperatures on the Southern Coast are more comfortable than in other parts of Southern Africa. Inland areas have a higher temperature contrast than on the immediate coast. Mountainous areas are coolest. Figure 3-8 shows highs in the 20s (° C), while Figure 3-9 shows lows in the upper teens.

Extreme highs have been recorded in the mid to upper 30s (° C). These are likely to have been caused by Berg winds or high pressure in the interior. Extreme lows have been in the single digits; these cold episodes are associated with strong frontal systems that pull in colder air.

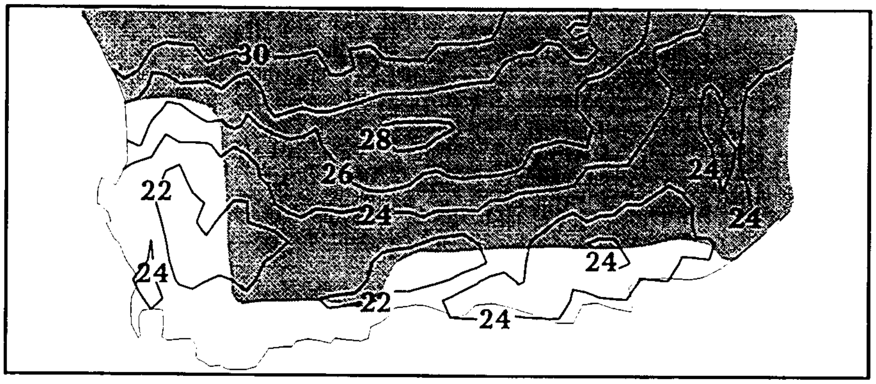


Figure 3-8. January Mean Maximum Temperatures.

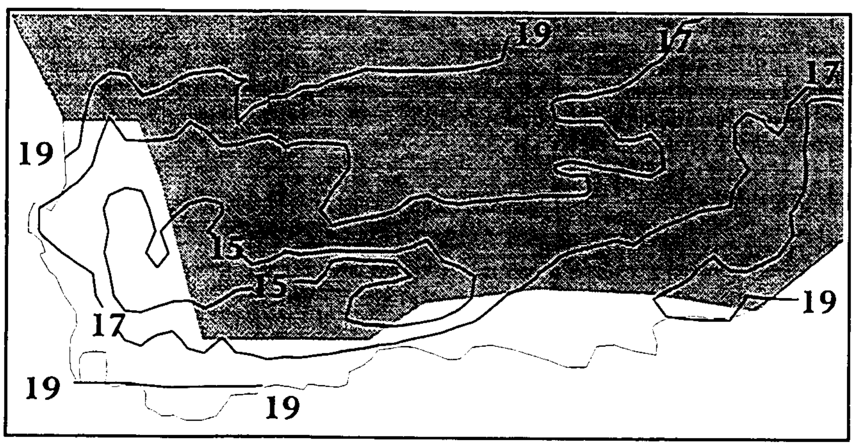


Figure 3-9. January Mean Minimum Temperatures.

**Other Hazards.** The southwestern coast is subject to rough seas and heavy swells; heavy surf breaks on the shores periodically throughout the year. Heavy and confused swells, mainly from the southwest, occur about 25% of the time in summer. The southernmost coast is also noted for heavy and confused swells and rough seas as the southwesterly wind blows against the current.

Swell direction conforms to the prevailing (southwesterly) winds. The frequency of the southwesterly swell is about 70%; the usual swell is moderate to heavy and of long or average length, but seldom short.

Although the predominant swell direction is southwesterly, summer "Southeasters" raise swells from the southeast that last for a day or two after the wind has dropped.

Northwesterly winds also raise long, heavy swells and rough seas. A low or moderate easterly swell often follows a period of northeasterly winds and may last for some time after the wind has changed to southwest.

Extremely high "rogue" waves occur off the coast. Although rare, they can reach trough-to-crest heights of over 15 meters. These waves are most frequent on the Agulhas-West Wind Drift boundary.

**General Weather.** Disturbances in the westerlies are the most common producers of fall weather. Frontal systems decrease through the season, but cut-off lows increase dramatically; the stronger of these can produce Black Southeasters with strong winds and rain. The influence of the South African High increases through the season, resulting in the region's best weather.

Strong disturbances in the easterlies, however, still occasionally reach the Southern Coast. When it is strong enough, an easterly wave can produce cloudiness and precipitation over the eastern half of the region.

**Sky Cover.** Cloud amounts increase steadily. Figure 3-10 shows that ceilings are most common in southern areas where frontal activity is greatest.

Primary cloud types change from cumuliform to stratiform through the season. Frontal systems show the classic "comma" shape; thick multi-layered clouds can extend to over 30,000 feet. Bases are usually 2,000-3,000 feet in clouds and associated precipitation.

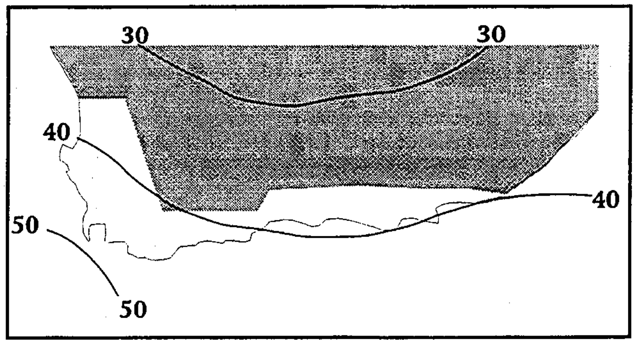



**Figure 3-10. April Percent Frequencies of Ceilings.**

Heavy banks of cumulus form when moist, cool air passes over the Agulhas Current. Cumulus develops soon after the passage of a trough, when the wind velocity has decreased and the frontal weather has passed. Once formed, the clouds remain as long as the winds blow from the southwest; showers and thunderstorms are occasionally embedded. The cloud bank is typically 25-30 km wide, and the average distance from the coast is from 65-80 km. The cloud bank is thickest in the east near Port Elizabeth, but thins toward Cape Agulhas.

Orographic lifting of moist, southerly air produces dense clouds that can shroud some of the mountain tops.

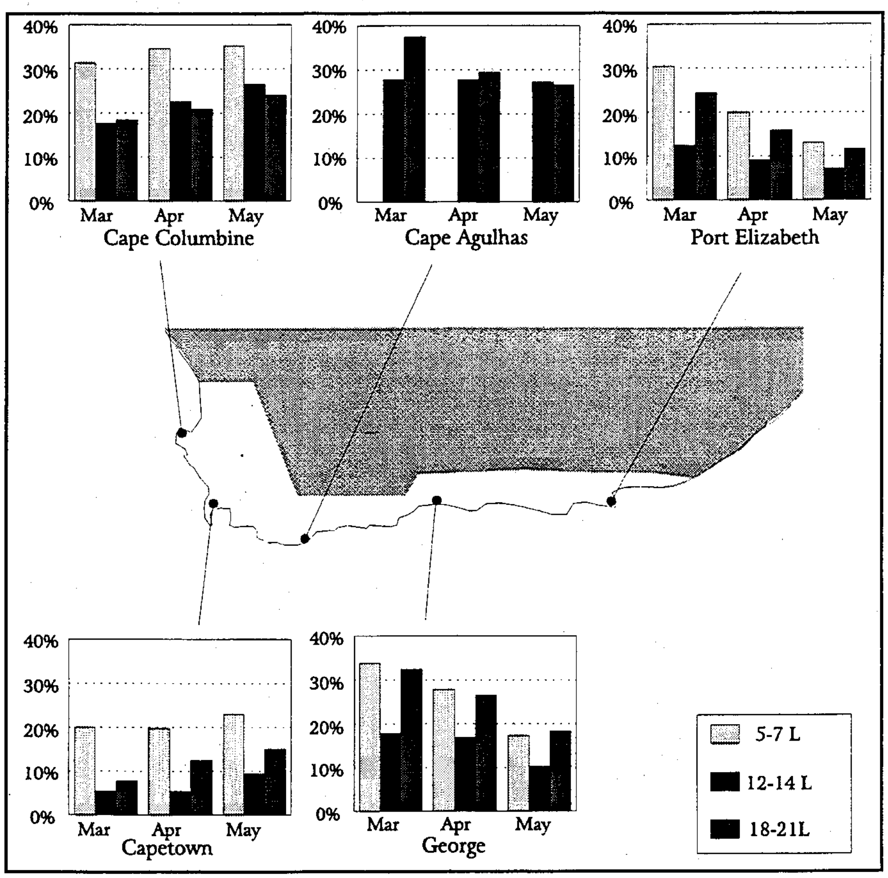



**Figure 3-11. Fall Percent Frequencies of Ceilings Below 3,000 Feet.** Cape Agulhas observations for 05-07L are not available.

Figure 3-11 shows that ceilings are least frequent near midday except for Cape Columbine, where fog formed over the Benguela Current causes low morning ceilings that lift slowly during the day.

**Visibility** is still very good. Fog causes most low visibilities, especially in the morning. The "fog season" is from late summer to early winter. There is more fog in the west than in the east because fog forms near the Benguela Current, causing the relatively high frequencies of low visibilities for Cape Columbine shown in Figure 3-12. Fog reduces visibility to less than 3,200 meters about 75-104 hours a month at Cape Columbine, but only 6-24 hours a month at Cape Agulhas.

March is the foggiest month in the east, while April is foggiest in the west. Fog formed in a southwesterly wind is more extensive and longer-lasting than fog formed with other wind directions. Fog can form even with strong winds, but usually only in a cooler and less stable air mass behind a cold front or occlusion. Surface cooling alone is not enough to produce fog; vertical mixing and radiative cooling from above are also required.

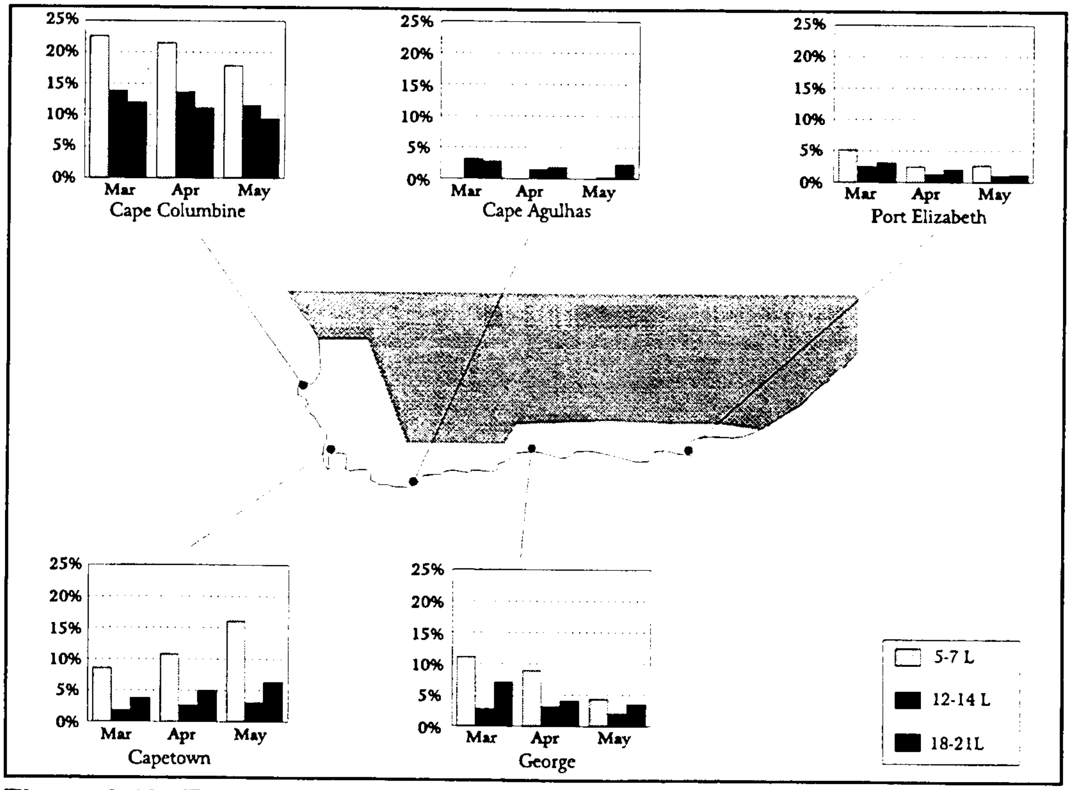



**Figure 3-12. Fall Percent Frequencies of Visibilities Below 4,800 Meters.** Cape Agulhas observations for 05-07L are not available.

**Winds.** Topography remains a major influence. Winds are strongest nearest the coast, and directions generally conform to the coastline. Only a weak land/sea breeze circulation remains in eastern areas. Winds are at the year's weakest during early fall everywhere except at Cape Agulhas. As frontal systems increase in frequency, mean wind speeds also increase. Winds are typically weakest in the morning and strongest in the afternoon. Interior areas usually have light morning winds that strengthen toward afternoon.

Black Southeasters occasionally occur in the fall. In April 1993, Capetown's airport reported wind speeds of 39 knots with gusts to 58 knots. Topographical influences generated even higher wind speeds elsewhere. Berg winds may also occur; see Chapter 2 for details.

Winds aloft are generally west to northwesterly. Mean speeds are about 30 knots at 700 mb and 50 knots at 300 mb.

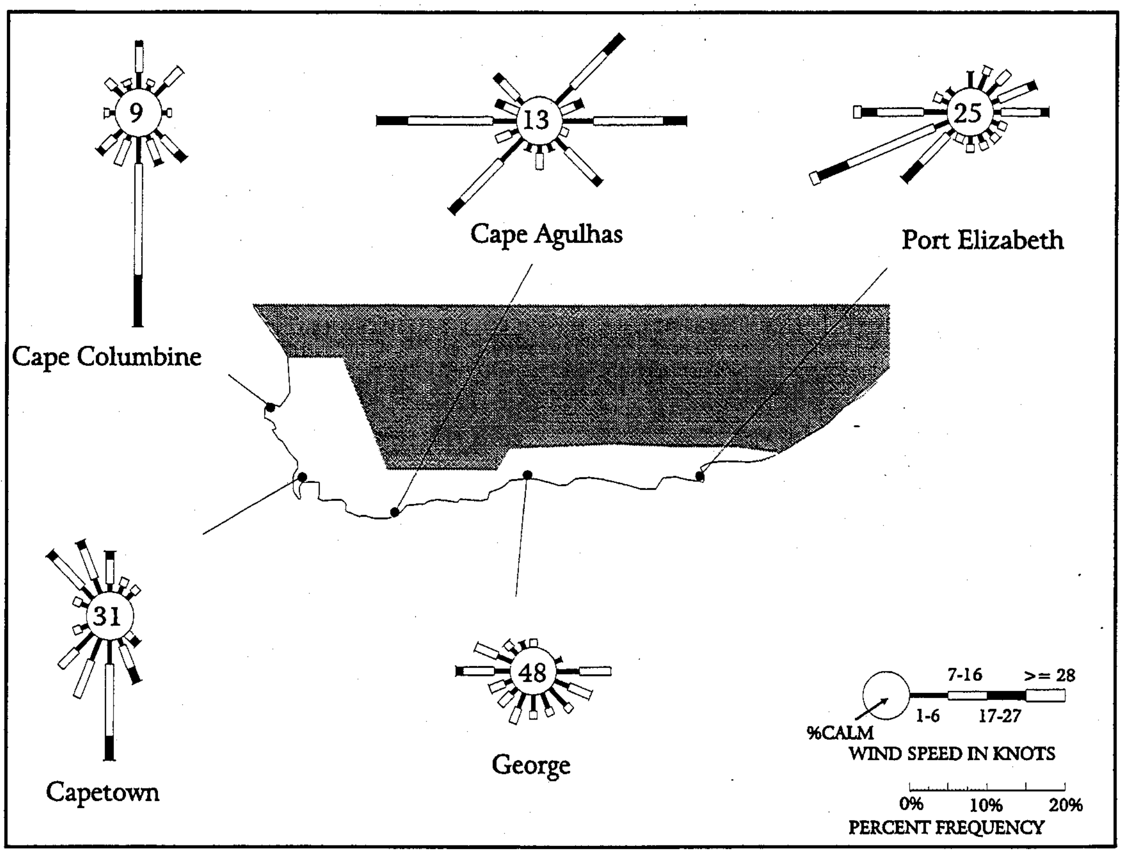



**Figure 3-13. April Surface Wind Roses.**

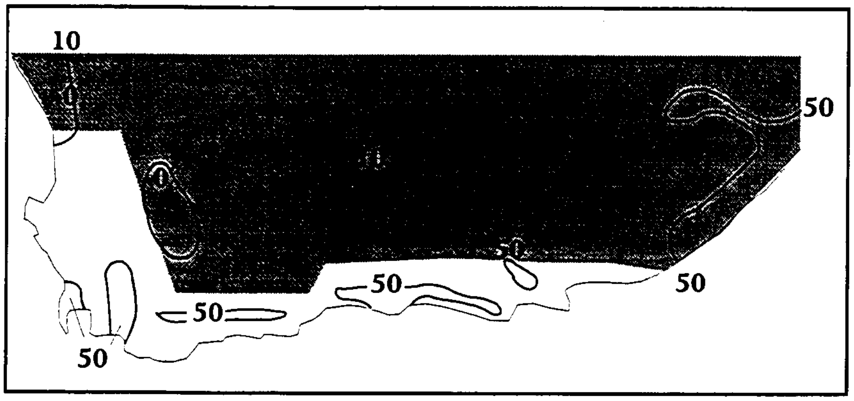


Figure 3-14. April Mean Precipitation (mm).

**Precipitation.** Monthly amounts increase steadily throughout the fall. Most precipitation falls as rain and rainshowers from frontal systems. Cut-off lows sometimes produce heavy rain. Topography also aids in the development of rainshowers. Southern areas receive more precipitation due to storm tracks and proximity to the mountains.

Even though many areas are very dry in April (see Figure 3-14), some western areas see a three-fold summer-to-fall increase in rainfall amounts. This is also evident in Figure 3-15, which show the number of precipitation days increasing steadily. In eastern inland areas and along the Little Karroo, the percentage of annual precipitation occurring in fall is actually at a maximum, primarily due to topography. Rainfall amounts increase at Port Elizabeth as precipitation intensity (but not occurrences) increases.

Snow sometimes falls in the mountains as early as April. Amounts are normally small, with no significant accumulations.

**Thunderstorms** are rare; when they do occur, it is mainly in eastern areas (see Figure 3-15). They are seldom severe; bases can be as low as 500 feet and tops as high as 30,000 feet.

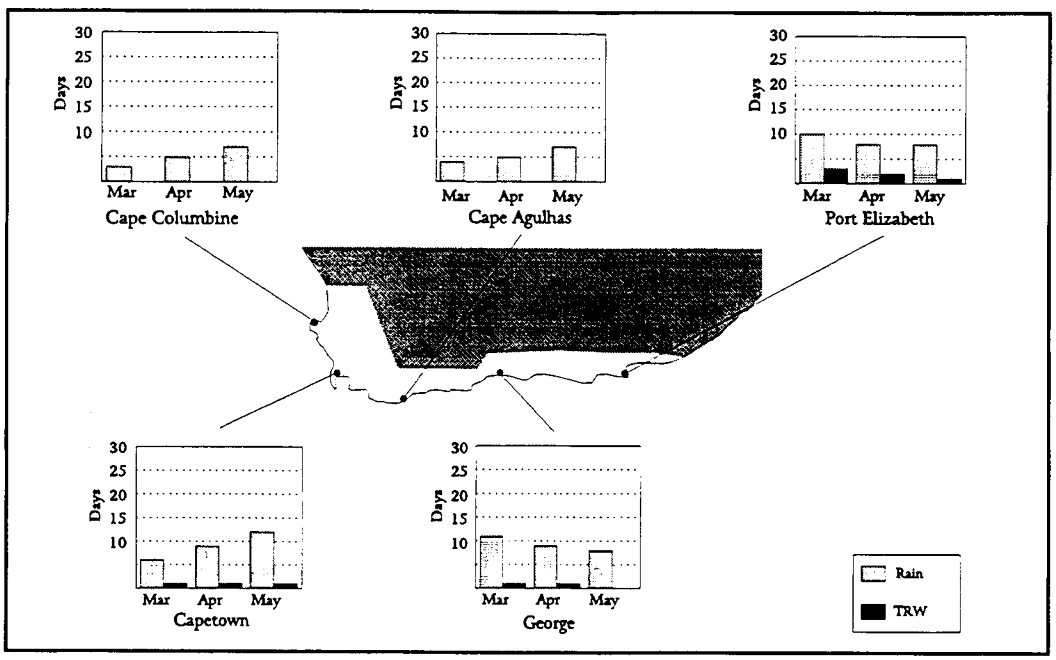


Figure 3-15. Fall Mean Monthly Rain and Thunderstorm Days.

**Temperatures.** Temperatures drop steadily during fall. April mean temperatures (Figures 3-16 and 3-17) are comfortable, but some higher elevations may be very cool at night. Lower elevations can have light frosts; higher elevations may have a hard frost by May.

Extreme highs reach the mid-30s °C and are probably caused by Berg winds. Extreme lows are in the single digits; in the higher elevations, extremes may be in the negative single digits.

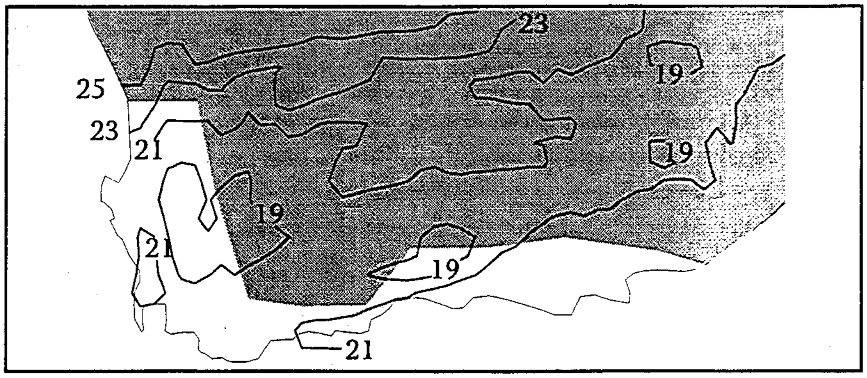



**Figure 3-16. April Mean Maximum Temperatures.**

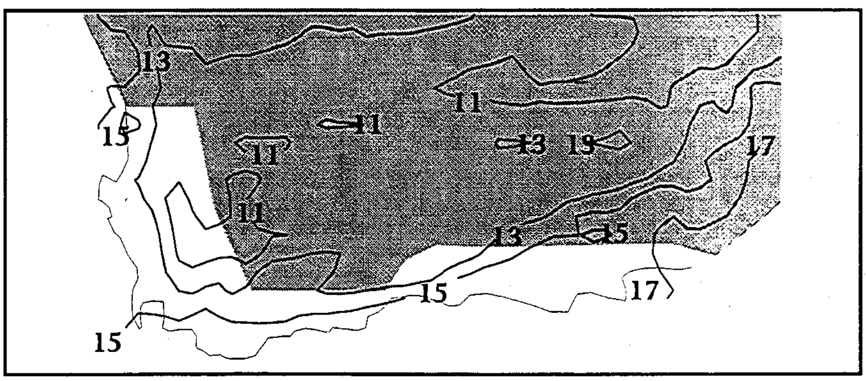



**Figure 3-17. April Mean Minimum Temperatures.**

**General Weather**. The South African High now dominates. Cold fronts bring in most of the unsettled weather. Strong cut-off lows are known to deliver localized extreme amounts of rainfall over inland areas. About 11 cut-off lows occur each year; one in five causes localized flooding. Divergent and subsident northerly flow ahead of fronts causes stable and generally cloud-free conditions, but low-level convergence along and just behind fronts can produce conditions favorable for convection.

Coastal lows and berg winds are common. Coastal lows form from the generation of cyclonic vorticity by easterly low-level flow off the high plateau. They usually form on the west coast and move southward to Capetown, then eastward and northeastward around the coast. All coastal lows produce warm offshore flow ahead of the system and cool onshore flow behind it. They seldom extend inland of the Cape mountains.

Hot berg winds blowing at more or less right angles to the coast usually accompany coastal lows; these winds, which are one of the most unpleasant features of the coastal climate, sometimes persist for many days until switching to the southwest. Cessation of the berg wind is accompanied by a large drop in temperature.

Southerly flow occurs with a strong zonal pressure gradient between a high to the west and a low the east. A trough in the westerlies at 500 mb is usually present. Light rain usually falls ahead of the upper-level trough. This pressure pattern also brings cold temperatures.

Tropical continental air from the north occasionally becomes unstable, bringing warm weather, convective clouds, rain on the coast, and thunderstorms inland.

**Sky Cover.** Winter has the greatest cloud cover; the highest amounts are in the west. Most winter frontal systems show the classic "comma" shape (see Figure 2-11). Nimbostratus with embedded cumulus and cumulonimbus make up the cloud layers of a cold front. Bases are usually 2,000-3,000 feet but they can go below 1,000 feet in precipitation. Tops can extend to over 30,000 feet.

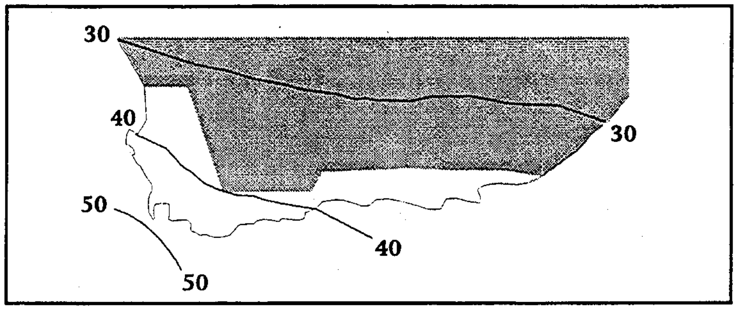



**Figure 3-18. July Percent Frequencies of Ceilings.**

After frontal passage, skies begin to clear as cold-air cumulus develops. With strong southeasterly winds blowing for a day or two, orographic lifting of moist air causes the slopes of the southern mountains to become shrouded in clouds. In eastern areas, with easterly winds in the rear of highs, overcast stratus and drizzle can last for 2 or 3 days.

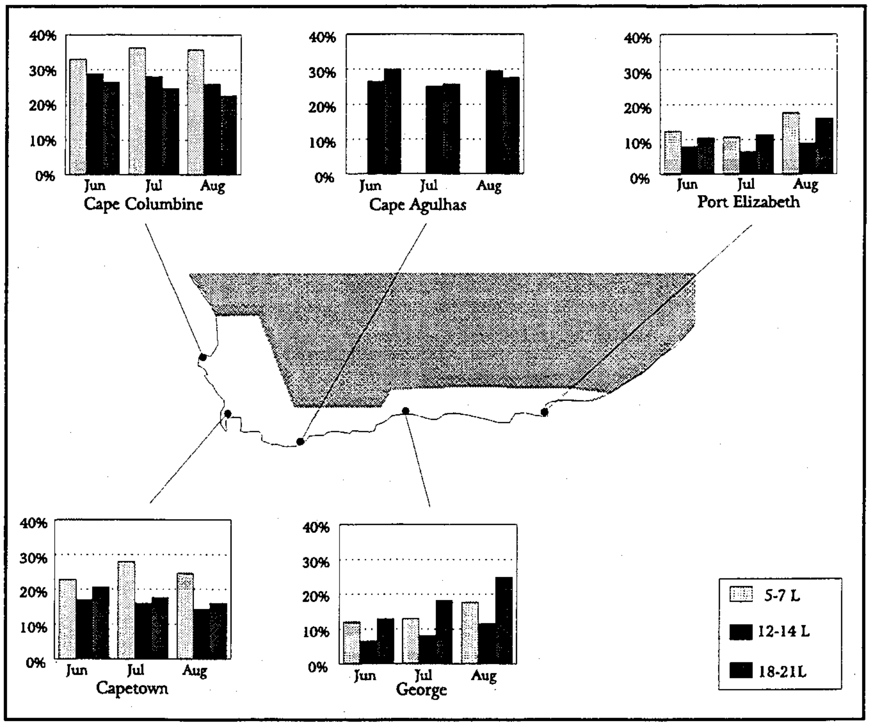



**Figure 3-19. Winter Percent Frequencies of Ceilings Below 3,000 Feet.** Cape Agulhas observations for 05-07L are not available.

Heavy banks of cumulus form when moist, cool air passes over the Agulhas Current. More clouds develop soon after the passage of a trough when the wind speed has decreased and the frontal weather has passed. Once formed, they remain as long as winds are from the southwest, accompanied by showers and occasional thunderstorms. The cloud banks are typically 25-30 km wide and 65-80 km from the coast.

Figure 3-18 shows higher frequencies of ceilings in southwestern areas due to frequent frontal passages; Figure 3-19 shows the same trend. Topography determines low-ceiling development.

Much of the morning cloudiness at Cape Columbine and northward is stratus formed over the Benguela Current; stratus is seldom more than 1,000 feet thick and often clears before noon.

Figure 3-19 also shows a diurnal variation; low ceilings are most common in the morning and evening. These variations are smaller than those of summer because of increased frontal influences.

**Visibility** is usually very good. Precipitation and fog are the primary restrictions. As shown in Figure 3-20, visibility is best to the south and east. Figure 3-20 also shows that low visibilities are most common in the morning and evening. On cold mornings, smoke and haze may restrict visibilities. Capetown and George each have 8-10 days a month with haze. At Capetown and Cape Columbine, visibilities are below 800 meters about 5% of the time.

In the west, the poorest visibilities occur when coastal fog forms over the cold water and drifts inland in the evening or early morning. Cape Columbine and Capetown each have about 10 days of fog a month. Thick mist or haze occasionally forms in valleys on calm nights; it remains for an hour or two after dawn.

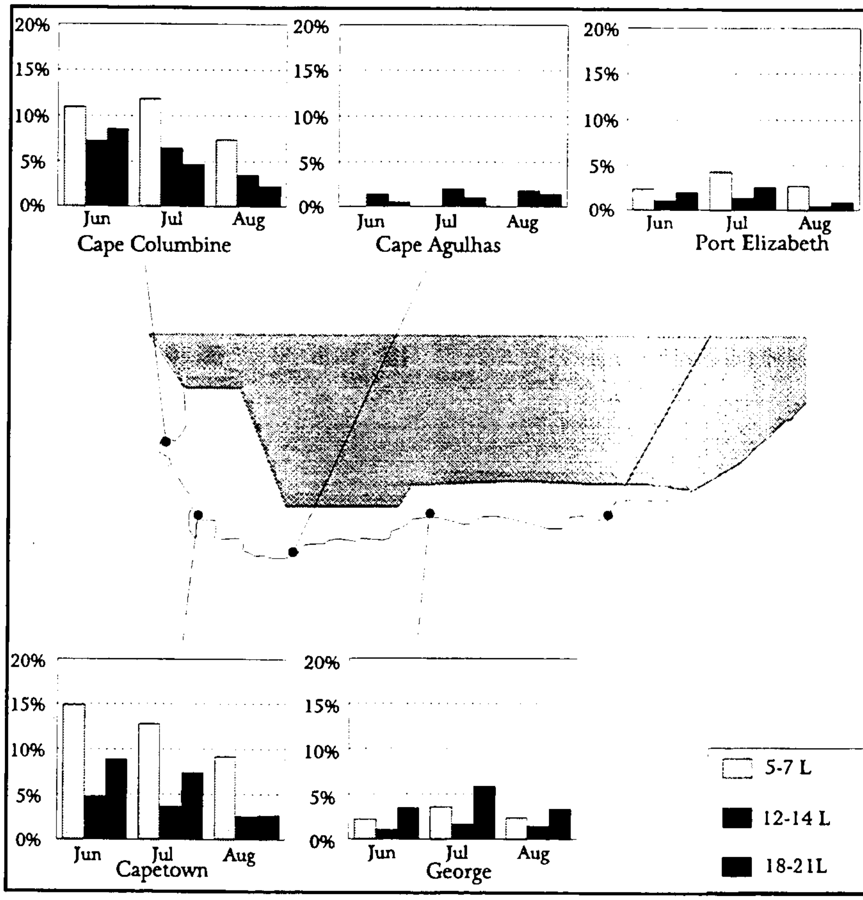



**Figure 3-20. Winter Percent Frequencies of Visibilities Below 4,800 Meters.** Cape Agulhas observations for 05-07L are not available.

In the east, fog only occurs about 2 days a month. Haze and ground fog are the most common causes of poor visibilities. Ground fog is seldom thick and rarely lasts past late morning. It forms on calm, clear nights and tends to drift down river valleys and often out to sea where, if the wind is light, it can remain for several hours before dissipating. Haze usually occurs with high pressure when winds are light and there is a strong inversion. Visibilities have been known to go below 1,600 meters in haze.

**Winds.** The coastline and the mountains modify surface winds. On the coast, winds conform to the trend of the coastline; that is, they are northerly and southerly on the west coast, and easterly and westerly on the south coast . The frequent passage of low-pressure systems causes the wide variations shown in prevailing wind directions (see Figure 3-21).

Winds are generally lighter than in summer, but strong winds can occur with the increasing number of synoptic systems. Inland areas are likely to have lighter winds. Winds are strongest in the afternoon. There is no appreciable land/sea breeze circulation.

Winds aloft are generally west to northwesterly. Speeds become slightly stronger in the lower levels, averaging 35 knots at 700 mb. At 300 mb, winds average 50 knots.

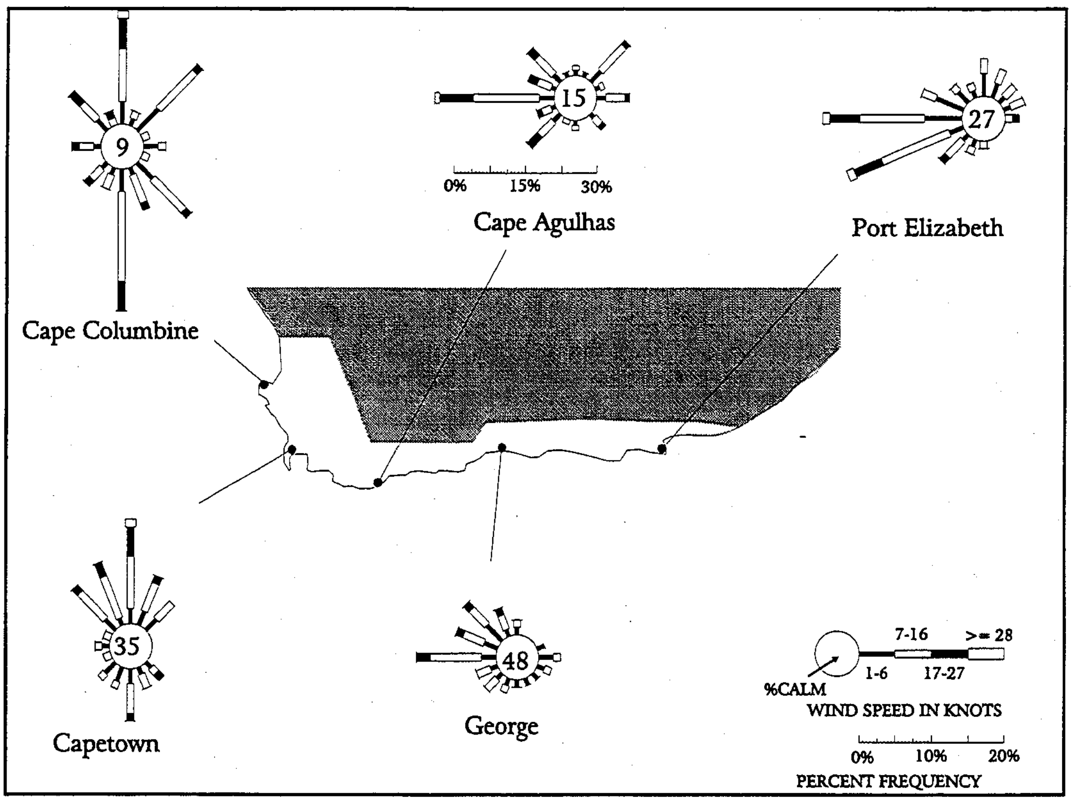



**Figure 3-21. July Surface Wind Roses.**

**Precipitation.** With greater frontal activity and more frequent low passages, winter has the highest rainfall amounts. In western areas, about 45% of the annual rainfall occurs during winter; in eastern areas, only 25%.

As shown in Figure 3-22, average precipitation amounts decrease from west to east because of decreasing frontal exposure. Topography enhances precipitation, causing the 100 mm and 50 mm average precipitation patterns shown.

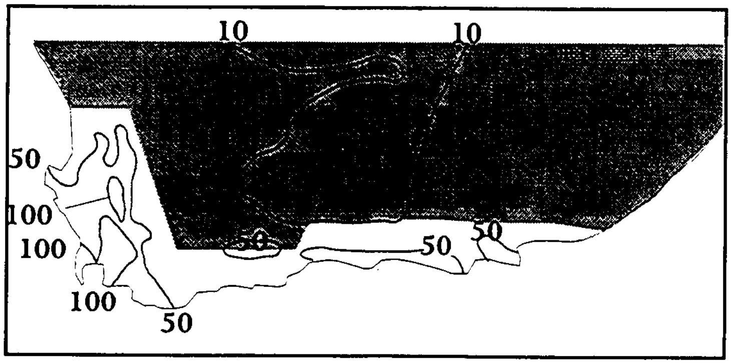


Figure 3-22. July Mean Precipitation (mm).

All areas have about the same number of days with rain (see Figure 3-23), but greater amounts fall in western areas. At Capetown, 20% of the rain falls at more than 13 mm/hour. Flash flooding is infrequent but it has occurred in the west.

Coastal areas have not recorded snow, but snow can fall in the mountains almost anytime between April and August; it can remain for 2 or 3 weeks before melting. Snow accumulations are usually less than 20 cm. Small hail is fairly common during showers that follow a cold front. It is usually soft and not destructive.

**Thunderstorms.** are rare, as indicated in Figure 3-23; they normally only accompany strong weather systems and are generally not severe.

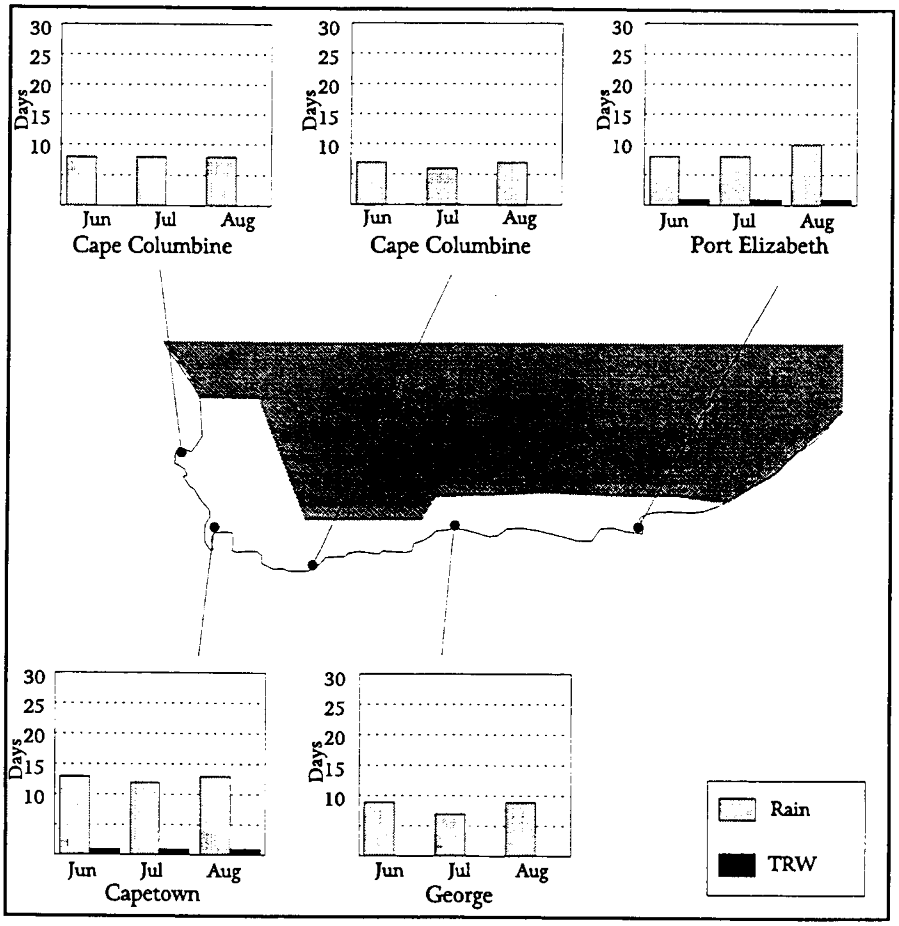


Figure 3-23. Winter Mean Monthly Rain and Thunderstorm Days.

**Temperatures.** The cold Benguela Current on the west coast and the warm Agulhas Current on the south coast influence winter temperatures (see Figures 3-24 and 3-25). Temperatures are lower in mountainous areas.

The cape peninsula and low-lying areas are almost free of frost. The coldest weather comes a day or two after a low, when skies clear and winds are calm. Extreme minimum temperatures range from 0 to 5° C on the coast to about -5° C in the mountains.

The warmest weather usually precedes a low when winds are strong and from the north. Berg winds can cause higher than normal temperatures. Extreme highs are in the upper 20s °C.

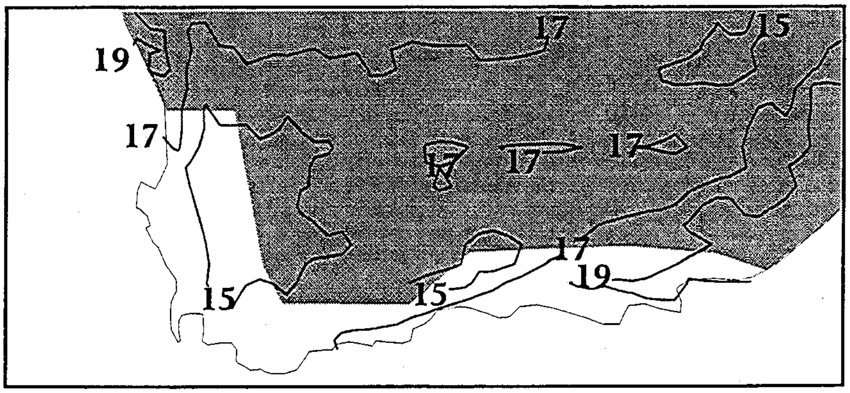


Figure 3-24. July Mean Maximum Temperatures.

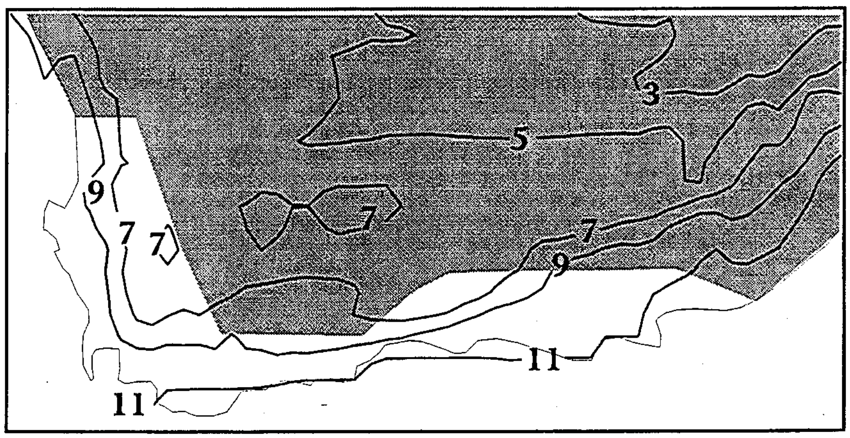


Figure 3-25. July Mean Minimum Temperatures.

**Other Hazards.** Rough seas and heavy swells occur throughout the season. The predominant swell direction is southwesterly. Heavy and confused swells occur about 35% of the time. The South Coast of Africa is noted for heavy and confused swells and rough seas where the southwesterly wind blows against the current, raising a rough breaking sea.

The direction of the swell conforms to the prevailing (southwesterly) winds. The frequency of the southwesterly swell is about 70%. The usual swell is moderate to heavy and of long or average length, but seldom short.

Northwesterly winds, especially gales of the winter months, raise long, heavy swells and rough seas. A low or moderate easterly swell often follows a period of northeasterly winds and may last for some time after the wind has changed to southwest.

Strong southwesterly winds behind frontal systems can generate the largest waves, which are commonly referred to as "Cape Rollers." These occur in the Agulhas Current and are especially hazardous to shipping. The largest waves have been reported to be 21 meters high.

**General Weather.** The South African High becomes less dominant. Disturbances in the westerlies bring most of the unsettled weather to the area. The frequency of cut-off lows decreases by about a third from winter.

Warm and dry clear weather is associated with ridging off the southwest coast. Extreme eastern areas may experience showers associated with the trough aloft east of the ridging. This pattern occurs most often in October.

**Sky Cover.** Frontal activity causes most ceilings, which are mostly stratus and nimbostratus with embedded cumulus and cumulonimbus. Bases of low ceilings rise through the season to around 3,000 feet; tops may extend to over 30,000 feet. Ceilings near mountains may be lower due to orographic effects. Ceiling frequencies in October are similar to those in July (see Figure 3-26).

Occurrences of ceilings below 3,000 feet decrease in spring; ceilings are rarely below 1,000 feet. Low ceilings are most common in the morning and evening (see Figure 3-27).

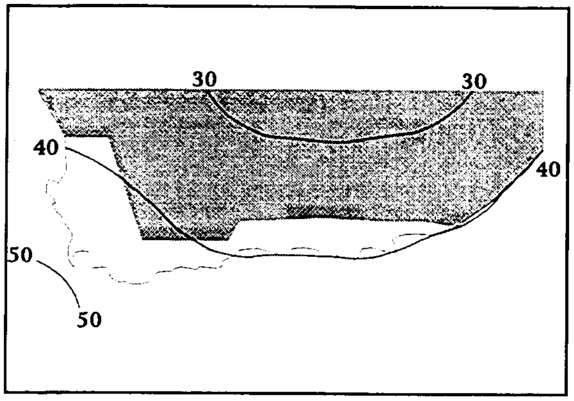



**Figure 3-26. October Percent Frequencies of Ceilings.**

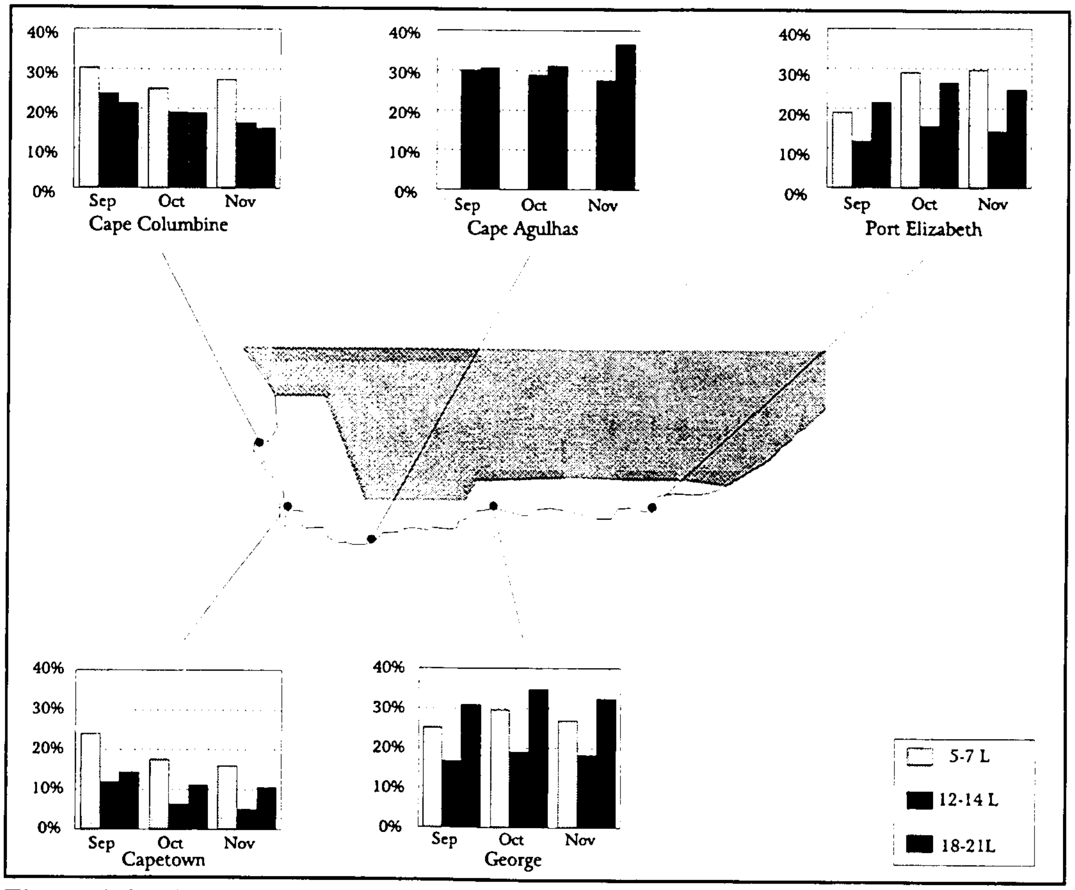



**Figure 3-27. Spring Percent Frequencies of Ceilings Below 3,000 Feet.** Cape Agulhas observations for 05-07L are not available.

**Visibility** is still very good. Fog and/or light rain or drizzle cause most morning visibility restrictions, but as the day progresses, restrictions become more likely due to precipitation. Western areas are more likely to have fog than eastern areas. Warm, moist air over the cool Benguela Current causes fog to develop along the west coast.

As shown in Figure 3-28, frequencies of visibilities below 4,800 meters are 10% or less. Frequencies are highest in the morning and evening.

Low visibility in sea-spray and pollution haze are most common at Capetown and George, occurring at each on about 10 days a month.

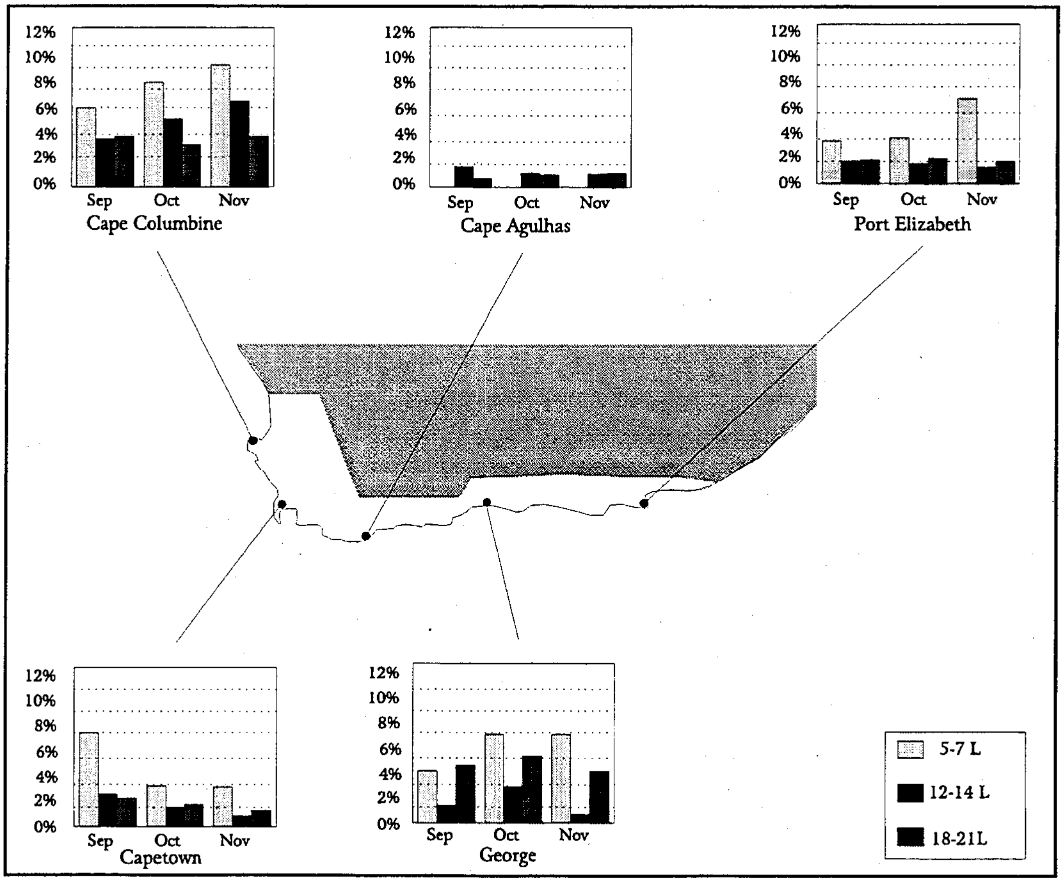



**Figure 3-28. Spring Percent Frequencies of Visibilities Below 4,800 Meters.** Cape Agulhas observations for 05-07L are not available.

**Winds.** Spring winds are similar to winter's, with directions conforming to the coastline (Figure 3-29). Winds are again dependent on location and strongest in the afternoon. There is no appreciable land/sea breeze circulation. Strongest winds are due to frontal systems. Early in the season, berg winds may occur over eastern areas. In the east, winds are at their strongest of the year. By the end of the season, the local wind known as the "southeaster" begins to appear.

Mountain/valley circulations begin to redevelop late in the season with increased heating.

Winds aloft are generally west to northwesterly. Mean speeds are about 30 knots at 700 mb and 50 knots at 300 mb.

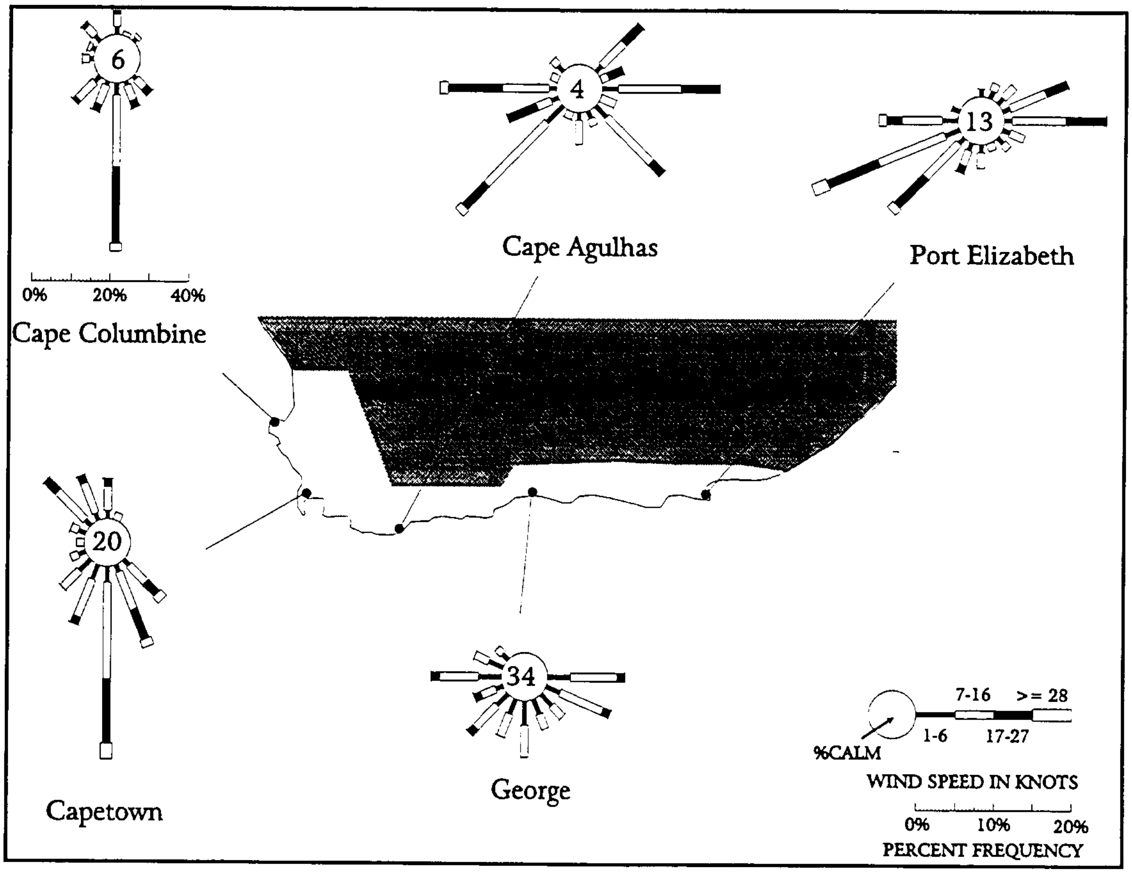



**Figure 3-29. October Surface Wind Roses.**

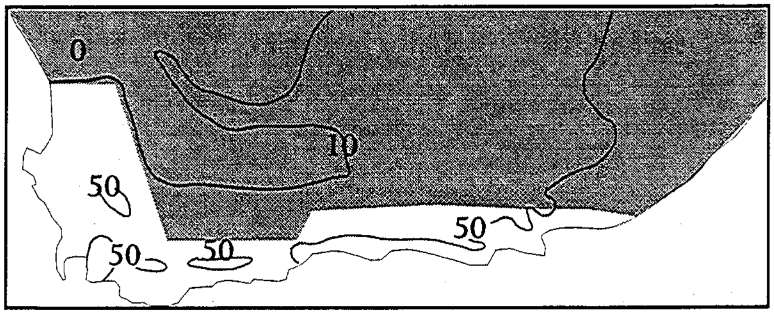


Figure 3-30. October Mean Precipitation (mm).

**Precipitation.** Amounts decrease in western areas as the frequency of frontal systems decrease. In western areas, about 20-25% of the annual precipitation occurs during spring. In the east, the percentages are about 30% of annual. Spring precipitation occurs primarily in the form of showers. Windward slopes receive more precipitation (Figure 3-30).

As shown in Figure 3-31, days with rain decrease by about half for western areas but remain the same in the east; this is because the "Black Southeaster" begins to affect the eastern areas. See the summer season for a detailed discussion.

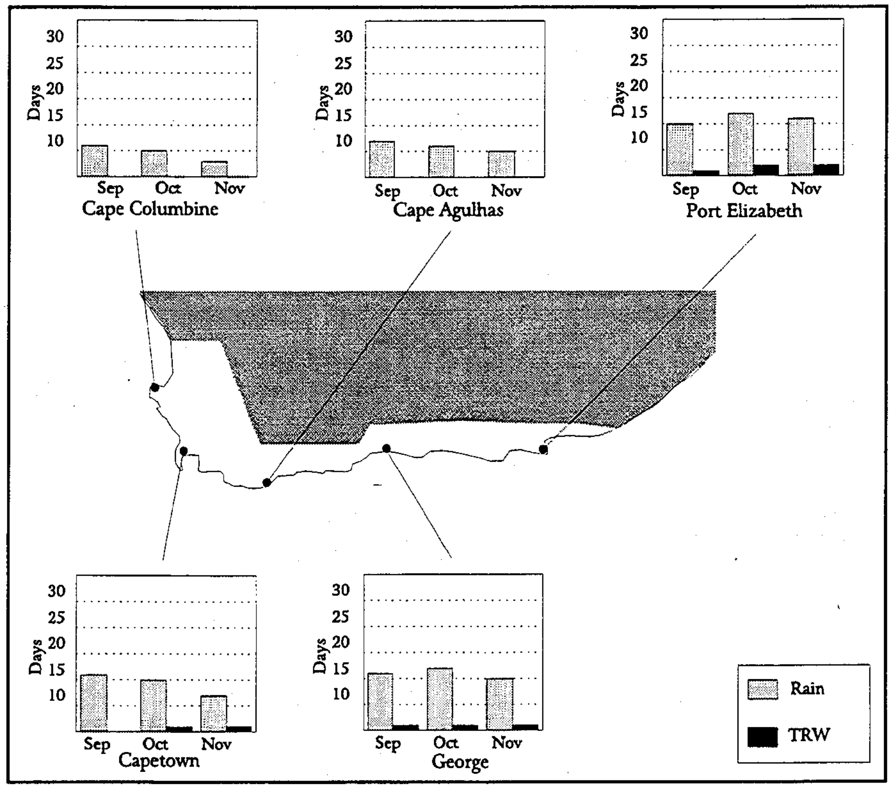


Figure 3-31. Spring Mean Monthly Rain and Thunderstorm Days.

**Thunderstorms.** As shown in Figure 3-31, spring thunderstorms are uncommon but increasing through the season. They are generally not severe.

Thunderstorms are more likely to develop over inland mountains, most often during the afternoon; they seldom last beyond early evening. Bases are around 1,000 feet, but can be lower at higher elevations; tops can exceed 30,000 feet .

**Temperatures**. As shown in Figures 3-32 and 3-33, spring temperatures are mild. Extreme highs are in the upper 20s to lower 30s° C, probably caused by berg winds. Extreme lows are 5-10° C, probably the result of strong frontal systems.

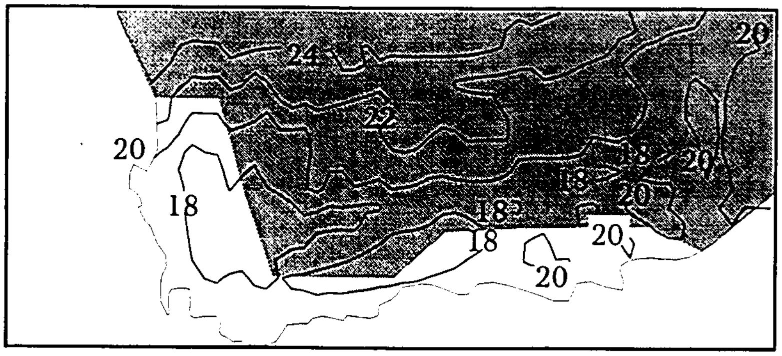



Figure 3-32. October Mean Maximum Temperatures.

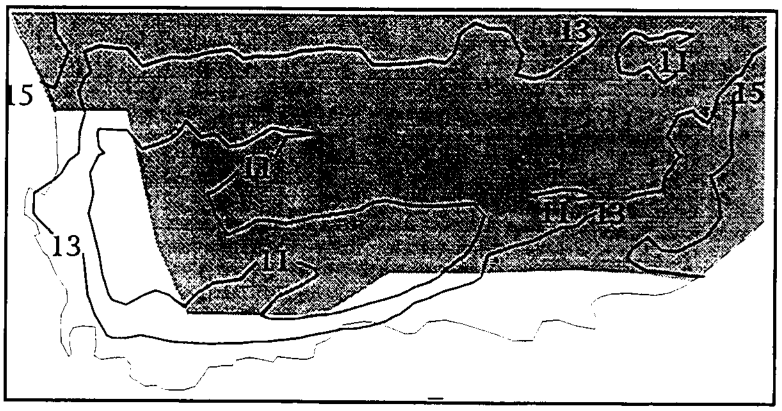
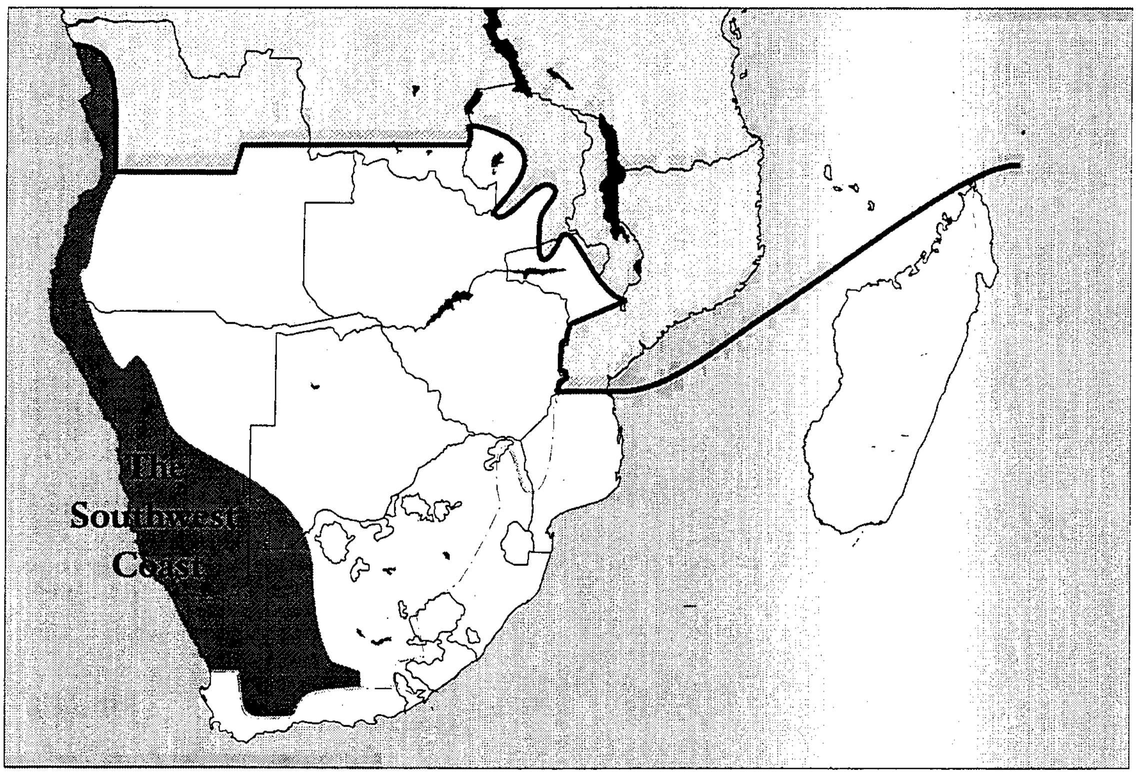



Figure 3-33. October Mean Minimum Temperatures.

## Chapter 4

# THE SOUTHWEST COAST

This chapter describes the geography, relief, major climatic controls, special climatic features, and general weather (by season) for Africa's southern Atlantic seaboard, and for the inland deserts of Namibia, southwestern Botswana, and the northwestern part of the Republic of South Africa (referred to in text as "South Africa").



## SOUTHWEST AFRICA GEOGRAPHY

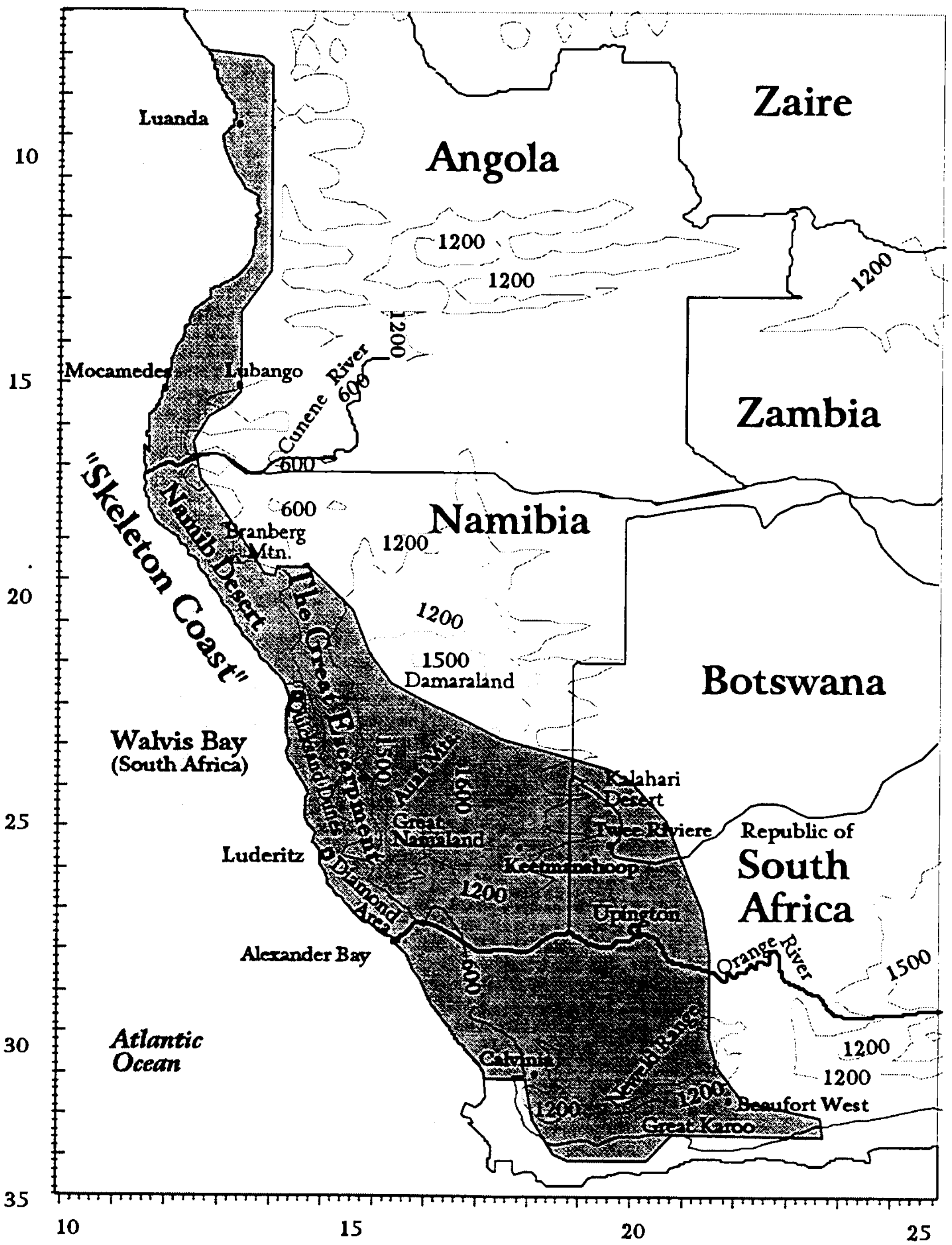



**Figure 4-1. The Southwest Coast of Southern Africa.**

Deserts dominate almost all of the Atlantic coast from western Angola through western South Africa. They extend about 1,960 km from north to south and average 100 km in width. The Namib desert is the largest at approximately 105,700 square km; a large part of the Namib desert is known as the "Skeleton Coast."

## SOUTHWEST AFRICA GEOGRAPHY

The Quicksand Dunes stretch for more than 350 km from near Walvis Bay south to Luderitz, and run inland from the Atlantic shoreline to the Great Escarpment. These yellowish-red dunes are ever-changing due to the constantly drifting sand, hence the name. Individual dunes can exceed 150 meters from base to crest. Dunes continue through Namibia's restricted diamond-mining area, which lies between Luderitz and the Orange River; this is one of the world's largest diamond sources.

The Great Escarpment (average elevation 1,050 meters) marks the inland edge of the Southwest Coast. To the east and southeast, the interior has many diverse surface characteristics that include broken veldt (grassland), rugged mountains, sand-filled valleys, gentle plains, and isolated peaks.

A series of mountain ranges comprises the Great Escarpment. Branberg Mountain is the highest, at 2,610 meters. The escarpment in Angola has a ridge line that exceeds 1,500 meters.

Central Namibia's Auas mountains (average elevation 1,500 meters) lie in the northeast interior. They separate Damaraland (in the north) from Great Namaland (in the south).

To the east, southwestern Botswana lies in the Kalahari Desert; this is mostly a flat tableland with elevations between 915 and 1,220 meters. The sandy Kalahari continues into South Africa, where there are large salt pans. Terrain to the south becomes more rugged; the Nuweveld Range has peaks above 2,000 meters.

The Great Karoo Desert lies south of the Nuweveld Range, with elevations below 1,000 meters. South of the Great Karoo, an area of folded mountains varies in height from 1,500 to 2,315 meters. The folds include an east-west depression called the "Little Karoo." Mountains along the southernmost portion of the region have peaks exceeding 2,240 meters.

**Rivers and Drainage.** Hundreds of small rivers, some intermittent, drain down the mountains to the coast. The Orange and Cunene Rivers are the largest and most important.

The 2,100-km Orange River separates Namibia from South Africa. Toward its mouth in the Atlantic, it flows through the diamond area. Sand bars and many shoals restrict river traffic. With many, often intermittent, tributaries, the Orange drains an area of about 610,000 square km.

The Cunene River separates Namibia from Angola. It flows westward for about 1,200 kilometers after rising in central Angola.

**Vegetation.** Short desert grasses and succulents—fleshy, cactus-like plants—are sparsely scattered over the region. Shrubs and thorn bushes grow in the interior; acacia trees thrive near rivers. Some parts of the Namib Desert contain no vegetation at all, while relatively dense patches grow in the region's northern fringes, in Angola. Many succulents are so small and well-camouflaged that areas appearing to be barren may actually be teeming with life.

## MAJOR CLIMATIC CONTROLS OF THE SOUTHWEST COAST

**General.** The subtropical ridge, the South-African High, the southeasterly trades, and the Benguela Current are the main controls; they cause stable conditions to prevail for most of the year. As a result, much of the area can go for years without measurable precipitation.

**Subtropical Ridge and South-African High.** The interior climate is controlled mostly by the subtropical ridge and South-African High, but the latter has more influence during the dry season. Subsidence from these highs, along with orographic effects on mountains bordering Southern Africa, result in the arid climate in the interior. The Congo Air Boundary sometimes lowers stability along the Great Escarpment; its position and strength fluctuate depending on other synoptic influences.

**Southeasterly Trades.** The trades and the associated Benguela Current dominate the coast. The trades dominate the south over 80% of the time; the north, about 50% of the time. The base of the associated inversion is at 300-900 meters; it is lowest in the dry season and on the central and southern coast, and highest in summer and on the Angola coast. Inversion tops range from 900-2,100 meters. The air is warm and dry above the inversion, but mild and humid below.

**Temperate Disturbances.** Cold fronts and troughs affect the entire region, but the South Atlantic High and the trades keep many from affecting the coast and the Great Escarpment keeps many others from affecting the interior. Cold fronts are more common than troughs in the dry season; the reverse is true in the wet season. Temperate disturbances are often preceded by coastal lows (see Chapter 2) that normally follow the coastline southward, then continue east around the African continent. They are sometimes overtaken by, and merge with, the disturbances. This is typically the only time that coastal lows cause measurable rainfall. The summer merger of a coastal low with a trough aloft may be correlated with increased tropical convection to the north. Abnormally frequent or strong lows may be tied to a weakening Benguela Current associated with an El Niño-like event in the Atlantic.

**Cut-off Lows.** These often form over the southernmost part of the region, but their effects are minimal because they usually move quickly east. Mostly, they affect Southern Africa east and southeast of this region, where northerly flow draws in moist, tropical air. When they occur, the southeast part of the Southwest Coast region may see brief periods of increased cloudiness and rare precipitation.

## SPECIAL CLIMATIC FEATURES OF THE SOUTHWEST COAST

**Mist Rain.** "Mist rain" is a local term applied to the extremely light drizzle that falls along the region's coasts. Although common, it is not measurable on a daily basis and does not show up in rainfall statistics. Even so, annual accumulations reach 25-50 mm, and it is the primary moisture source for most coastal vegetation. Generally, mist rain does not reach beyond 55 km inland; it rarely reaches 80 km inland, depending on the synoptic situation and strength of the flow.

**Benguela Current.** The Benguela Current enhances the sea breeze and produces considerable sea stratus and sea fog; these are especially common on the coast from southern Angola through central Namibia. Stratus is more common than fog because of a generally standard lapse rate from the surface to 1,000-2,500 feet. Necessary lift is provided by mechanical turbulence. Stratus bases are usually at 400-800 feet. Stratus and sea fog tops are near the trade-wind inversion base. The stratus is lowest in the morning and over coastal waters. Most fog occurs over coastal waters; sea fog forms along the more arid coastal sections.

The typical sea stratus/fog cycle begins during the evening as patchy stratus moves onshore and grows in coverage through the night. It generally reaches 40-80 km inland and often lowers to fog in many areas. After dawn, the stratus/fog usually rises, then dissipates seaward by about 0900L; erosion correlates with the daily sea-breeze onset. The fog and stratus persist out to sea and are visible from the coast, while sky conditions are good onshore. At their normal daily minimum, stratus and fog recede seaward to 8-16 km, often blanketing the sea for 150-350 km westward. On the coast during World War II, aircraft avoided sea stratus by routinely taking off and landing toward the interior.

Generally, sea stratus/fog that persists beyond 1100L signals deteriorating weather. This happens on mornings when synoptic onshore flow, caused by disturbances such as coastal lows, temperate westerly surface troughs, and cold fronts, sets in.

In most cases during the day, the onset of synoptic onshore flow brings sea stratus over the coast, followed by very light drizzle (mist rain) and a lowering of the stratus as sea fog pushes onshore. A nocturnal onset can bring fog along with the stratus. Mist rain is most likely to occur when winds are under 10 knots, typically overnight and in the morning. Gloomy weather can move inland through doorways such as the Orange River Valley. Even near the coast, however, there are ridges high enough to prevent weather from reaching nearby depressions, which often remain clear and dry. These conditions persist until the synoptic pattern changes, which can take days.

**Buster Winds.** This is a local term applied to strong onshore flow north of coastal lows. Busters bring cool, moist air and cause sudden but brief—usually less than an hour—20 to 30-knot winds, with gusts to 50 knots. Stratus and fog rapidly invade the coast.

**Berg Winds.** Bergs are katabatic, easterly winds that bring exceptionally high temperatures, low relative humidities, and cloud-free skies to the coast. Berg winds can reach 35 knots. Duststorms are possible, usually over and seaward of the Quicksand Dunes. Temperatures have reached 48° C on the coast in the south and have been known to increase by 17 degrees within 2-3 hours of berg onset. Bergs occur with strong easterly flow, usually south of coastal lows or northwest of strong highs. Bergs can last anywhere from a few hours to several days, with afternoon interruptions. They strengthen overnight, peak in the morning, and begin to weaken by noon as sea breezes form and eventually overcome them. Temperatures on the coast peak before noon, then drop sharply; temperatures inland peak a little later and become higher because sea breezes reach there later. Slope winds sometimes complicate matters. Nocturnal berg temperatures on the coast range from about normal to a little higher, depending on berg strength. Easterly flow aloft, at or above 1,500 meters, sometimes signals an upcoming berg. Bergs are very rare in Angola and most common south of Luderitz, Namibia.

**General Weather.** The trade winds and the Benguela Current are the dominant coastal wet-season controls. In the early wet season, the trades are most pronounced and the Benguela Current at its yearly strongest. The Benguela's presence is sporadic in the late wet season. Sea breezes enhance or dampen synoptic flow; they are up to 900 meters deep. There are occasional early and late wet- season berg winds; they do not occur in the middle of the wet season since the flow at that time tends to be parallel to coasts rather than perpendicular to them.

The interior is generally clear and dry, but the South African High (weaker than in the dry season) allows some convection to form. Most convection is isolated and over the mountains. Late in the wet season, tropical cyclones near Madagascar or in the Mozambique Channel occasionally cause the South-African High to strengthen more than normal.

Interior convective activity moves toward the coast when flow aloft is easterly. Although rare over most of the region, thunderstorm lines in Angola can move westward or southwestward. These lines of convection typically form in tropical air and perpendicular to 3,000-6,000 meter flow. They usually form in the afternoon over the African interior and appear most often to be associated with interactions between tropical and temperate disturbances. Although the disturbances themselves do not always move westward, the organized activity they produce sometimes does; this results in strong turbulence and heavy rain. Intermittent rain from low to mostly middle clouds falls east of the lines. When there isn't enough moisture, afternoon development dissipates into mostly mid-level cloudiness. Usually, the coast only sees increased cloudiness at all levels.

From middle December through late January, Angola is affected by a stable period called the "little cacimbo." There are a number of possible explanations, but the little cacimbo probably results from a slight strengthening of the South African High, which impedes the passage of disturbances while bringing relatively dry flow. The brief increase in stability might also be the result of Angola's low latitude, making the sun's lowest wet-season angle of incidence in December (see precipitation discussion). The little cacimbo may also be due to a slight and brief drop in coastal water temperature.

Cold fronts and surface troughs affect the region on 8-12 days a month, but they reach north of the Orange River less than 4 days a month and very rarely reach northern Namibia. They are most common in the early and late wet season. As they approach, sea stratus and very light drizzle may occur on parts of the coast, but most areas have clear to scattered skies. A distinct cloud band and isolated precipitation usually accompanies the disturbances; an occasional rainshower or thunderstorm may form on the southern coast or in the interior. Cold fronts are followed by brief gusty winds, abrupt cooling, and mostly cloudy skies; cloudiness decreases rapidly when and where onshore flow is lost. Although fronts do not reach Angola in the wet season, they, along with troughs, can interact with and enhance the effects of tropical disturbances there.

Other causes of instability include upper-air waves in the westerlies, cut-off lows, the Congo Air Boundary (CAB), and the Near Equatorial Trough (NET). Short waves and cut-off lows mostly affect the interior with briefly enhanced cloud cover and occasional isolated rainshowers and thunderstorms. The CAB may enhance convection along the western Great Escarpment. The NET does not enter the region, but it can move near enough to enhance convection in northern Angola.

**Sky Cover.** The Southwest Coast is intensely sunny. The only significant sky cover occurs in the morning along the coast in the northwest, causing the high frequency of ceilings shown in Figure 4-2. In Angola, low, middle, and high clouds associated with inland afternoon and evening thunderstorms occasionally rival morning sky cover.

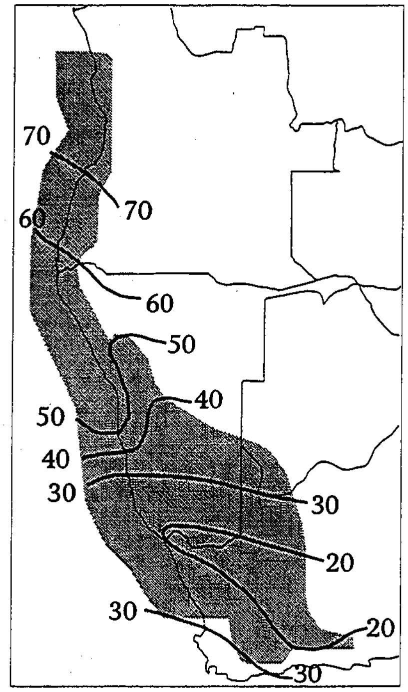


**Figure 4-2. January Percent Frequencies of Ceilings.**

Stratocumulus and cumulus, with occasional stratus, are the most common low clouds along most of Angola's coast. Stratus is most common at the start of the wet season and during the "little cacimbo." Most afternoon cumulonimbus remains inland. Sky cover on the northern and central Angola coast ranges from broken in the morning to scattered-to-broken in the afternoon. Inland, afternoon convection often makes skies broken or occasionally overcast.

Stratus is the predominant coastal cloud type from southern Angola south. Sky cover on the northern and central Namibia coast is normally broken-to-overcast in the morning and scattered-to-broken in the afternoon. Bases are at or below 800 feet, with tops at 1,000-2,000 feet. With persistent, strong, onshore flow, stratus (or fog) persists day and night, generally with bases below 500 feet and sometimes on the surface. Low-ceiling frequencies are shown in Figure 4-3, next page.

Temperate disturbances cause mean coastal sky cover from southern Namibia south to range from scattered-to-broken in the morning to scattered in the afternoon. Sea stratus may continue or thicken with onshore flow ahead of temperate disturbances, but sometimes, with no onshore flow, skies are clear. Isolated cumulus is possible ahead of disturbances in the extreme south and in the interior; rare cumulonimbus sometimes forms ahead of them inland. A distinct cloud band accompanies most temperate disturbances; it can include cumulus, stratocumulus, coastal stratus, isolated cumulonimbus, altocumulus, and cirrus. Stratus predominates on immediate coasts, increasingly so to the north; cumulus is most common in the interior. Post-frontal cold-air advection can bring cumulus, stratocumulus, and altocumulus along coasts. Weaker temperate disturbances bring more stratus to immediate coasts if there is onshore flow.

Inland, skies are clear-to-scattered day and night, except in the mountains on the edge of the Great Escarpment, where afternoon convection brings scattered-to-broken skies. Most afternoon cumulus clouds quickly dissipate into mid-level cloudiness. Lenticular clouds can form near higher mountains with a rare mountain wave.

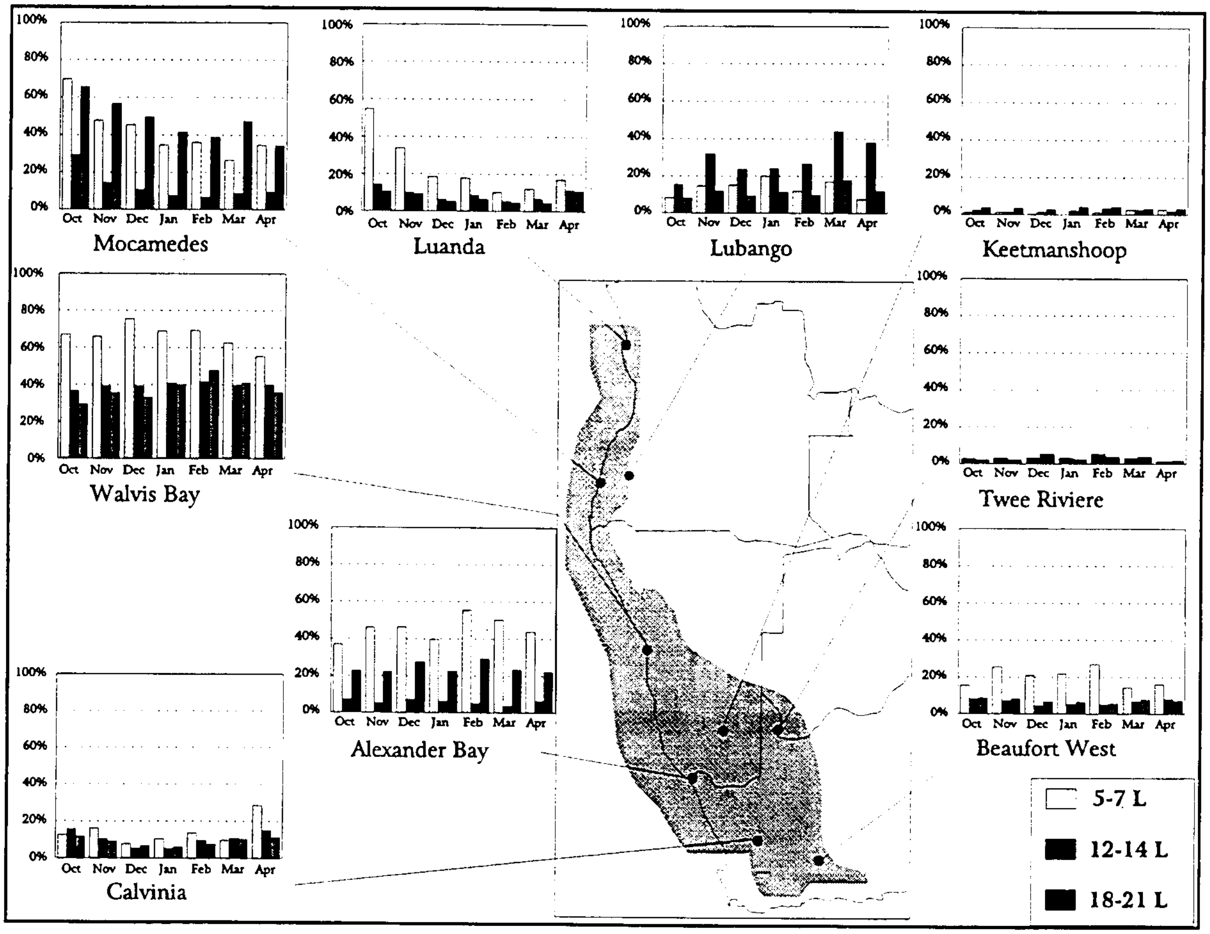



Figure 4-3. Wet-Season Percent Frequencies of Ceilings Below 3,000 Feet.

**Visibility.** Morning fog (most often advection fog off the Atlantic) reduces visibilities on the coasts of Namibia and South Africa. Morning frequencies of visibilities below 1,600 meters range from about 5% on the coasts of northern Namibia and South Africa to 10-20% on the central and southern Namibia coast, except in April, when frequencies increase to 15-35%.

Afternoon visibilities are seldom below 1,600 meters on most of Namibia's and South Africa's coasts except near the Quicksand Dunes, where dust, duststorms, and haze contribute to frequencies near 10%; late-season frequencies exceed 15%. Dust/duststorms and haze also reduce visibilities occasionally during the day on the coast of South Africa. An occasional rainshower or rare thunderstorm may briefly drop visibilities below 1,600 meters on the coasts of South Africa and Angola. Angola has most of its fog during the "little cacimbo." Figure 4-4 shows frequencies of visibilities below 4,800 meters.

Drizzle enhances fog restrictions on the entire coast. Salt haze lowers visibilities below 8,000 meters near the coast, especially beneath strong inversions. Heat-induced mirages are common throughout the coastal deserts. Radiation fog occasionally forms near the coast, eroding to the east when and where land breezes form.

Inland, visibilities are generally good except along the escarpment's western face, where isolated slopes are affected by radiation fog near the base of the trade-wind inversion. Radiation fog also forms near rivers, such as the Orange; this is an infrequent but significant occurrence since it affects places suddenly and unexpectedly. Daytime dust and haze are common, and occasional raised dust greatly reduces surface and flight visibilities. Duststorms occur occasionally, generally in the interior's extreme south. Infrequent rainshowers and thunderstorms can lower afternoon and evening visibilities to near 800 meters.

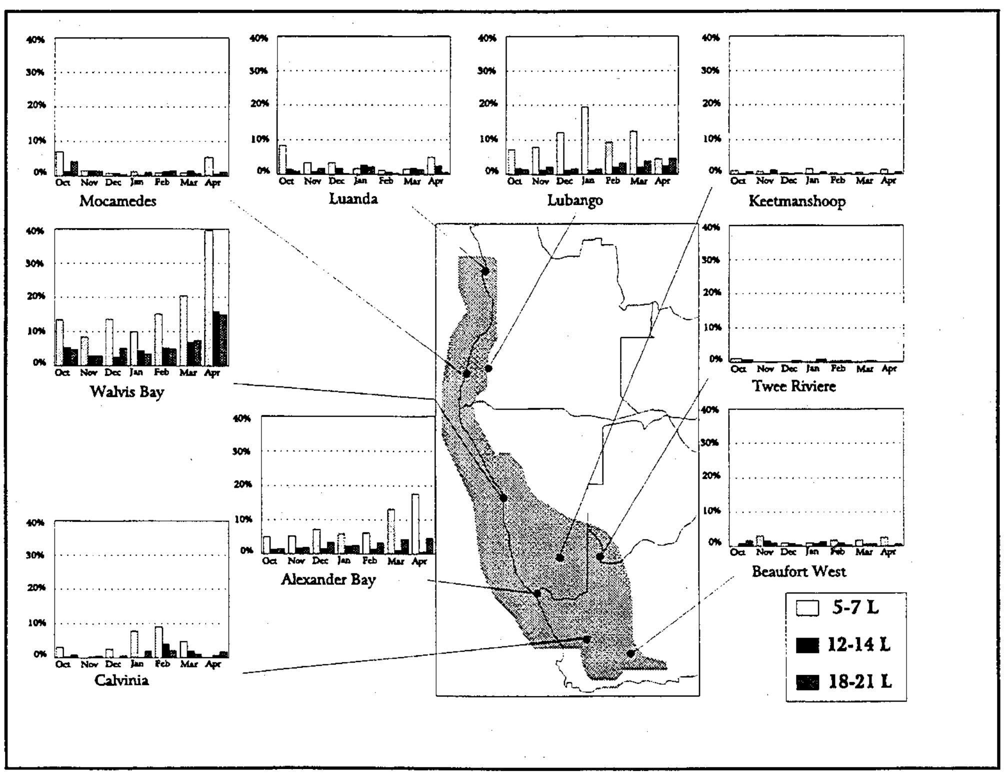



**Figure 4-4. Wet-Season Percent Frequencies of Visibilities Below 4,800 Meters.**

**Winds.** The trades, strongest near the southern Namibia coast, cause southerly winds to prevail well out to sea. They, along with sea breezes, are important along the coast (Figure 4-5). A typical day west of the escarpment begins with calm mornings or rare, very light land or slope breezes. A sea breeze forms with daytime heating. Winds back to southwesterly and speeds rise to 10-25 knots by 1300L. The weakest winds are to the north; the strongest are near the Orange River.

After sunset, winds back to easterly and speeds fall, establishing the typical morning wind pattern overnight. Temperate disturbances can disrupt this cycle south of Luderitz, causing westerlies or northwesterlies 5-15% of the time.

Sporadic light morning land breezes and rare early season berg winds cause the coast's infrequent easterlies. In Angola and the interior, easterlies (which can be strong and gusty) are usually due to thunderstorms. Wind directions are more variable inland, but most often southwesterly.

Mountain/valley breezes are common. Interior winds during nights and mornings are typically calm, with occasional light slope winds. Afternoon speeds in the interior are 5-15 knots, but stronger in the south and where flow is channeled through passes.

The strongest winds are on the coast between Walvis Bay and Alexander Bay, where sea breezes and the trades reinforce each other. Further enhancement can occur with onshore synoptic flow, like the very brief "busters" that occur north of some coastal lows. Winds near Luderitz reach 35 knots 20-30% of the time in early and middle wet-season afternoons; later in the season, winds are this strong less than 10% of the time. Southward on the coast, winds reach 35 knots on about 10% of early and middle wet-season afternoons, but on less than 5% of *late* wet-season afternoons. Northward, speeds decrease rapidly; 35-knot peaks are rare on the coasts of northern Namibia and Angola. Similarly, the region's interior rarely sees gusts above 35 knots. Thunderstorms cause peak winds in the interior; strong downbursts are possible.

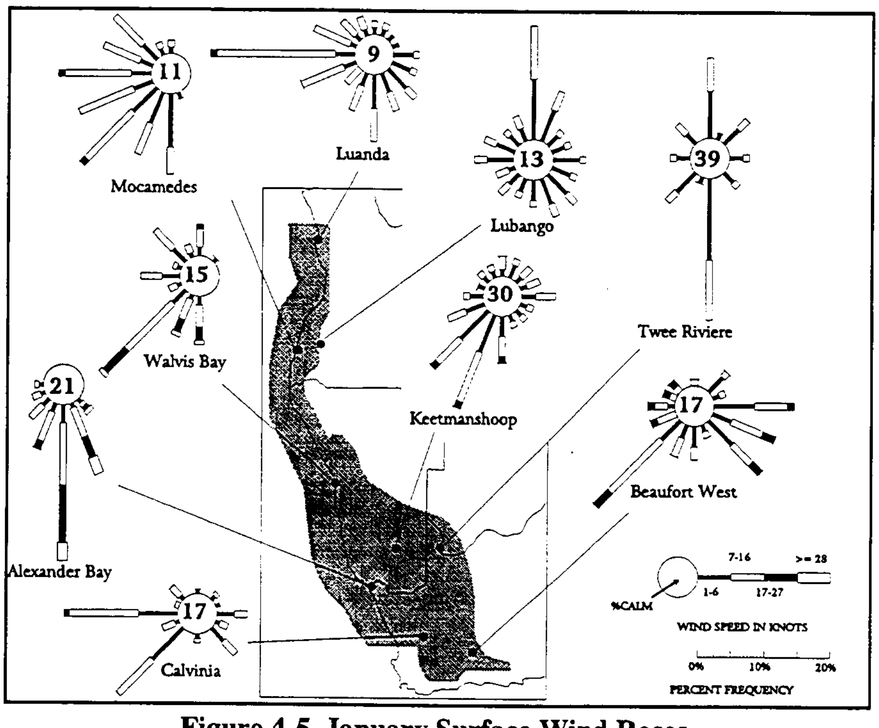



**Figure 4-5. January Surface Wind Roses.**

**Winds Aloft.** Coastal winds aloft are usually southwesterly below the trade-wind inversion and northwesterly to northerly above, especially in the south. Speeds range from under 10 knots north to 15-20 knots south both above and below the inversion.

At higher altitudes, winds are much stronger in the south where gradient flow is dominant (see Figure 4-6). Interior winds at low altitudes vary, most often with a westerly component, but flow at higher altitudes is similar to that over the coast.

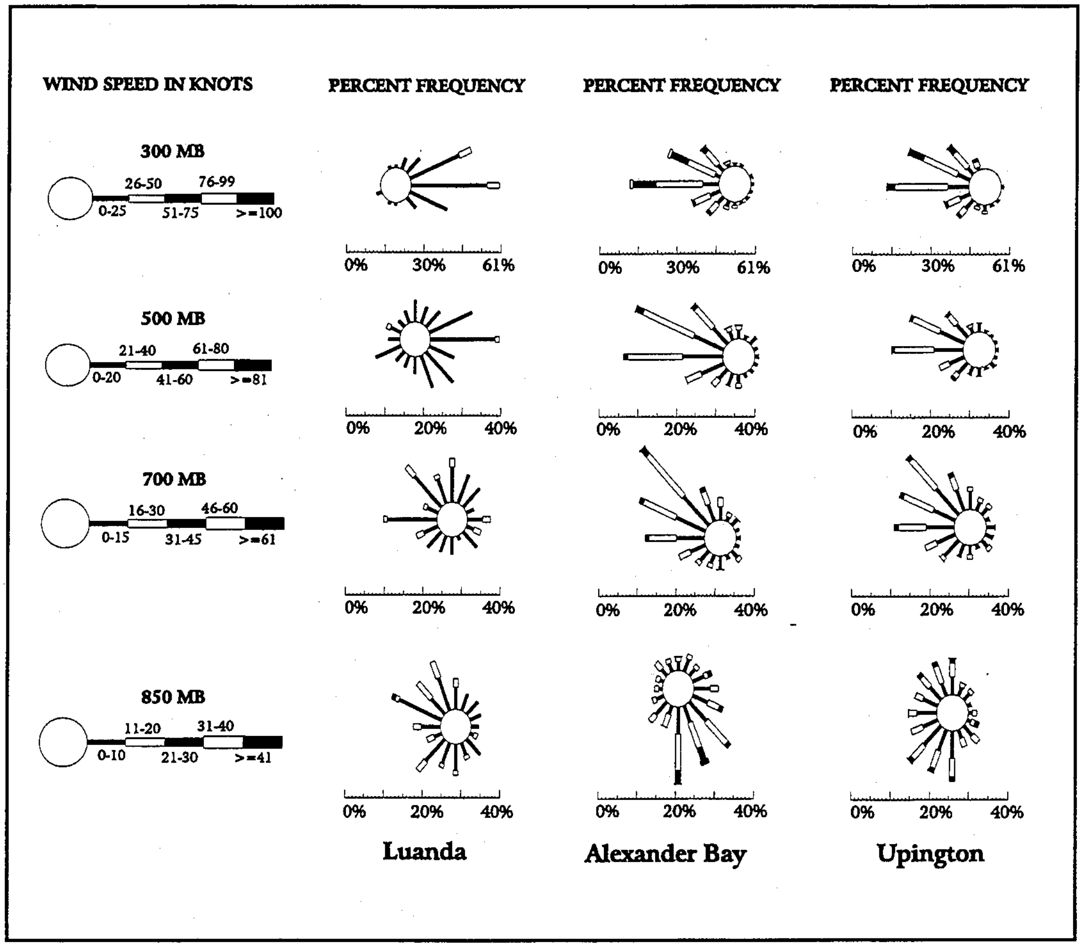



**Figure 4-6. January Upper-Air Wind Roses.**

**Precipitation.** Accumulations are low in Namibia and South Africa; less than 10 mm a month is recorded on the coast, and only about 50 mm is recorded in January along the interior's northern and eastern fringes (see Figure 4-7). Amounts in Angola, however, increase through the wet season from about 25 mm in October to 75-150 mm in April (see Figure 4-8). The higher amounts in the north are due mainly to interactions between tropical and temperate disturbances, enhanced by afternoon heating and orographics.

Tropical squall lines produce heavy rainfall in Angola. In the south, a single frontal passage can bring 50 mm of rainfall near where the Orange River passes through the Great Escarpment.

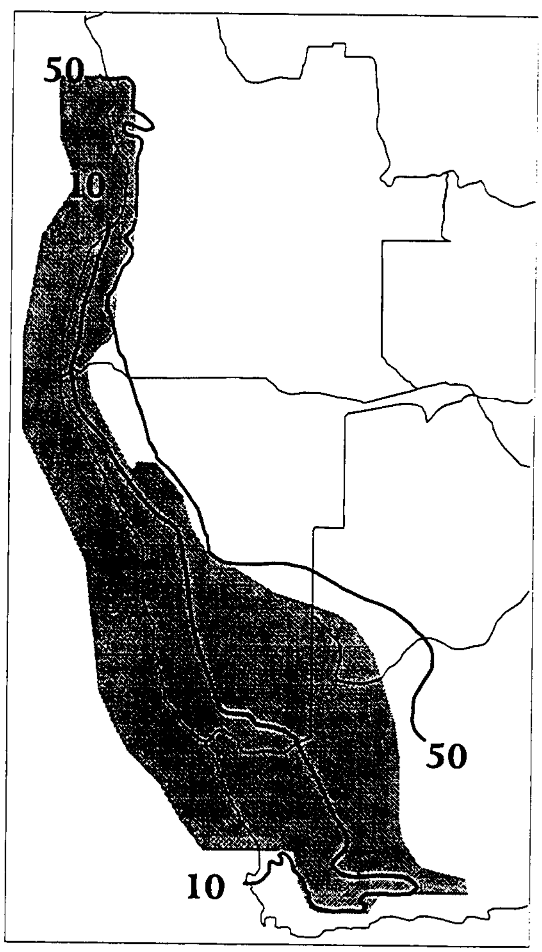



**Figure 4-7. January Mean Precipitation (mm).**

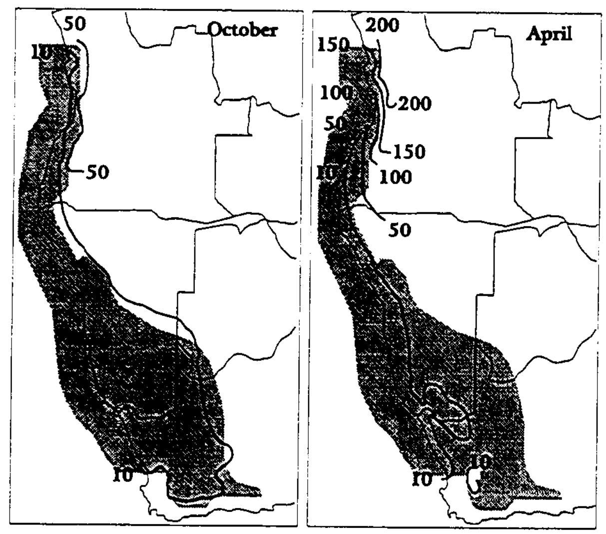



**Figure 4-8. October and April Mean Precipitation (mm)** The data does not fully reflect "mist rain."

Similar or greater amounts should be possible along much of the escarpment due to temperate disturbances to the south, tropical disturbances to the north, or (especially) a combination of the two in the central and northern portions.

Temperate disturbance precipitation is mostly patchy and remains close to the disturbance itself, but occasional light drizzle and rare showers are possible nearby. Drizzle is confined to the coast and the western face of the escarpment, while showers are only possible in the interior, along the southern escarpment, and on the southern coast. Virga is frequent. Cells often dissipate quickly as the dry air makes them spread out into middle and high cloudiness.

Showers produce the only measurable precipitation, but the coast's morning "mist rains" are more common. Since mist rains are not always reported as precipitation (they are often perceived as abnormally damp fog), they are not fully accounted for in Figure 4-9. They moisten surfaces 5-10 days a month on much of the coast, but generally penetrate no more than 55 km inland.

Measurable wet-season precipitation falls most often on the Angola coast and in the interior south to 30° S. In Angola, rainfall peaks are split by the "little cacimbo." They fall early and (especially) late in the season. The interior's peak rainfall comes after the early wet season.

Showers and thunderstorms peak during afternoons and evenings, while drizzle and or mist rain peaks in the mornings. Nocturnal showers can occur over Angola and its coastal waters. Rarely, they accompany temperate disturbances in the interior and south of the Orange River.

**Thunderstorms.** Most afternoon cumuliform development is either capped by an inversion or is dissipated because of dryness. The considerable coastal stability prohibits thunderstorm development on Namibia's coast, and allows only rare cells on the coasts of South Africa and southern Angola.

Peak development is in the early and late wet season in Angola and in the mid-to-late wet season in the interior. Figure 4-9 shows wet-season thunderstorm days at various locations.

Thunderstorms are most common on the mountains of the escarpment, where orographic effects enhance daytime heating and instability. Divergence aloft is often necessary for development. Temperate disturbances cause isolated cells to develop in and along the front.

Individual cells usually last less than an hour, with new development equatorward of old cells. Thunderstorms in the south generally move from the west or southwest, but those in the north can move in any direction. Tops can reach 60,000 feet. Disturbances, both tropical and temperate, can cause rare wet season squall lines.

Thunderstorms can bring hail, very rare tornadoes, and brief periods of heavy rain and gusty winds to the interior. Hail falls on 1 to 4 days during the wet season in the south and southeast, but mostly early in the season. Hail is of the soft "graupel" type in the southwest, but typical hard hail falls in the southeast. The strongest thunderstorms form in the early wet season when disturbances bring relatively moist low-level flow beneath dry westerlies aloft.

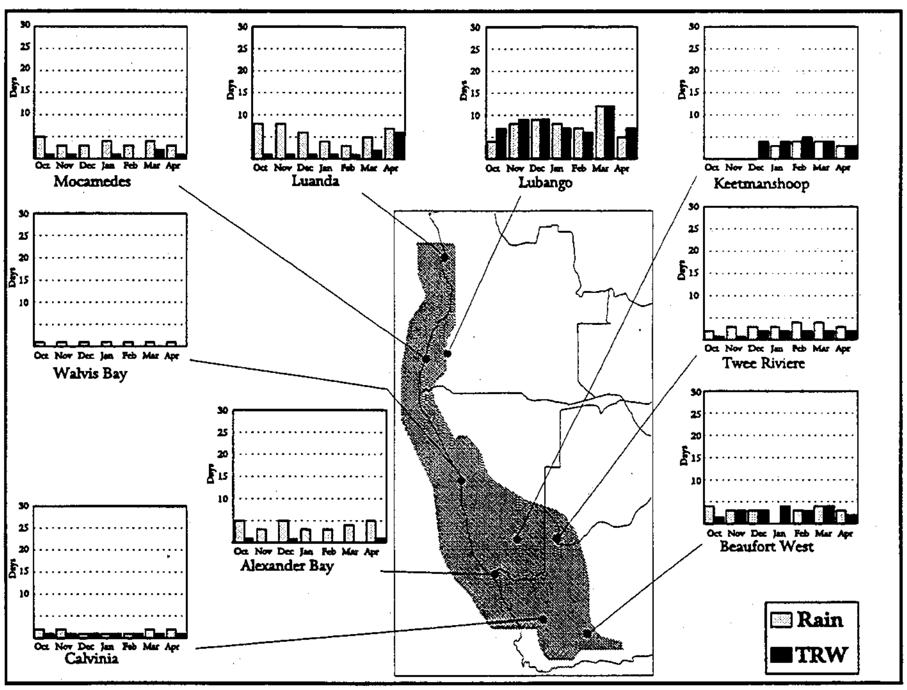



**Figure 4-9. Wet-Season Mean Monthly Rain and Thunderstorm Days.**

**Temperatures.** The ocean moderates coastal temperatures, but the interior remains dry; temperatures consequently show much greater diurnal variation, but generally vary little from day to day since wet-season weather systems are weak. In the north, temperatures actually fall from mid December to mid January because the sun reaches its southernmost point in late December. The sun's return northward causes February through April to be Angola's warmest months.

The highest temperatures near the coast are usually recorded before the daily sea breeze begins. This is usually by noon on the coast, but later in the day with increasing distances inland. Ridges prevent sea breezes from reaching some valleys and depressions, allowing daytime temperatures to resemble those in the interior. Temperatures just 30 km inland average about 10 degrees higher than on the coast. Mean coastal highs vary greatly, ranging from 15-25° C in Namibia and South Africa to 20-30° C in Angola (see Figure 4-10). Mean interior highs range from 20° C to 35° C; high elevations are mildest. Extreme highs on the coast are usually associated with early and late wet-season berg winds; 48° C is known to have been measured near the southern coast. Interior extreme highs are milder, at from 40 to 43° C.

Temperatures on much of the coast fall little overnight because sea fog and stratus limit radiative cooling. Diurnal variations on the coasts of Angola and Namibia are less than 5 degrees throughout the wet season. Nighttime temperatures fall more inland, since sky cover comes later or not at all, especially beyond about 30 km from the coast.

Mean lows on and near the coast range from 10 to 20° C in South Africa and Namibia to 15-25° C in Angola (Figure 4-10). Air in the interior is dry and cools freely at night; low temperatures are like those on the coast. Mean interior lows range from 10 to 20° C in the early and late wet season to 15-25° C in the middle; high elevations are coolest.

Extreme lows vary greatly by location and month. Below-freezing temperatures occur in the southern interior behind early and late-season cold fronts. Extreme lows on the coast range from 5 to 15° C in Namibia, South Africa, and southern Angola to 15-25° C in the rest of Angola. Extreme interior lows range from below freezing to about 10° C in the early and late wet season. In the middle of the wet season, the interior's extreme lows range from about 5° C in the south to 15-20° C in the north.

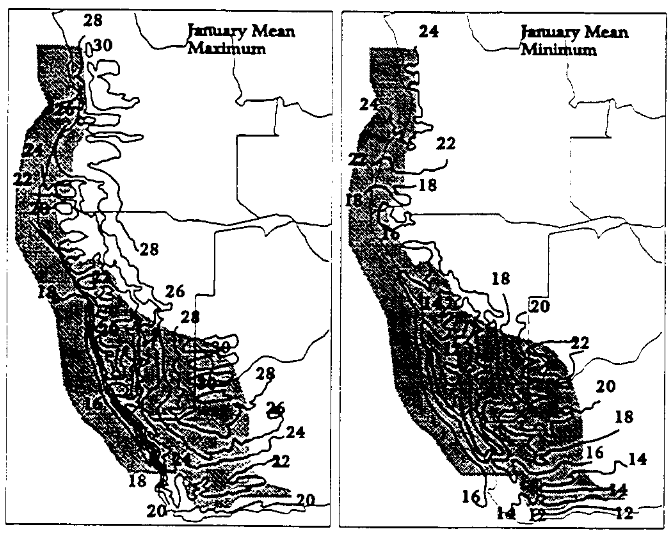



**Figure 4-10. January Mean Maximum and Minimum Temperatures.**

**Other Hazards.** Suspended dust can reduce inflight visibilities to below 1,600 meters. Sandstorms in the Quicksand Dunes can block roads and railways with large sand dunes. Dust-devils are common in the interior during afternoons. Flash floods are known to occur near highlands in Angola and near the region's southern mountains.

Dry river beds anywhere can fill quickly and unexpectedly as water drains from many miles away where heavy rain is falling.

Large breaking sea swells cause difficult ship navigation near shores, especially along the coasts of South Africa and southern Namibia.

**General Weather.** The trades dominate the coast north of 27-28° S; temperate systems dominate the south. The Benguela Current, although weaker than in the wet season, is still effective where the trades affect the coast. Sea breezes still form, but they are shallower (less than 600 meters deep) than in the wet season; berg winds have significant dry-season effects.

The South African High dominates the interior climate. It can dictate the weather for up to 2 weeks at a time as intensely sunny, dry days prevail. The inversion averages about 2,400 meters MSL.

Temperate disturbances interrupt this weather pattern, most frequently from July to September. On the southernmost coast, disturbances often bring several days of cloudy and breezy weather. Temperate disturbances affect southern coasts 8-12 days a month, but less than 6 days a month north of Walvis Bay and less than 4 days a month in Angola. Cold fronts do not reach Angola, but their resulting surface troughs and troughs aloft may briefly increase sky cover.

Temperate disturbances have their greatest effect on southwestern mountains, where upslope winds enhance their effects. Disturbances reach the interior nearly as often as on the coast, but they are considerably drier and weaker. The interior gets mostly increased cloud cover, but precipitation falls occasionally. Cut-off lows can cause briefly increased cloudiness and occasional light precipitation.

Coastal Angola is affected by periods of wet fog and drizzle that form over the Benguela Current. This dry-season phenomenon is attributed mainly to the South Atlantic High and its trades pushing the tropical weather belt well north of the area. This is not a constant condition, but it runs in cycles of several days.

Angola is, on rare instances in the dry season, affected by interactions between temperate and tropical disturbances.

**Sky Cover.** Dry-season skies are most often clear above 10,000 feet MSL; middle and high clouds only accompany disturbances. Sky cover is greatest in southern Angola and northern Namibia (Figure 4-11); it ranges from broken in the morning to scattered-to-broken in the afternoon. Although stratus is common, it is not as common as in the wet season (Figure 4-12, next page). Bases are usually 400-800 feet; tops, 1,500-2,000 feet.

In Angola, May is the least cloudy month of the year. Broken-to-overcast skies are common in the morning from June through September; stratocumulus prevails in the afternoon with bases at 1,500-2,500 feet and tops at about 5,000 feet.

Scattered skies dominate southern Namibia's coast, where the trades and Benguela Current have much less effect. Clouds increase again near and south of the Orange River, where temperate disturbances are more common. These disturbances bring stratus, cumulus, stratocumulus, and altocumulus. The stratus moves over the coasts, where there is onshore flow near disturbances and coastal lows. Except for the stratus, pre-frontal skies are usually clear. Cold fronts, however, produce cold-air advection that forms mostly stratocumulus; scattered cumulus and altocumulus may follow cold fronts. Weak, post-frontal air masses can push against the escarpment and produce several days of coastal stratus. The disturbances themselves can be accompanied by multilayered clouds. Disturbance-related stratus and stratocumulus can move through the valleys of southern Namibia and South Africa (such as the Orange River Valley) to about 150 km inland.

The escarpment and interior are mostly clear-to-scattered, except on southwestern slopes where cloud cover is about the same as (or is slightly greater than) South Africa's coastal sky cover. Most interior cloudiness accompanies disturbances, usually as bands of cumulus, stratocumulus, and altocumulus. Disturbances are usually preceded and followed by clear skies. Cut-off lows may bring brief, multilayered clouds to the southeast. Otherwise, interior skies are generally clear except for late in the dry season, when afternoon cumulus becomes common on mountains. Interior cloud bases are roughly 1,000-2,000 feet and tops are mostly below 10,000 feet MSL.

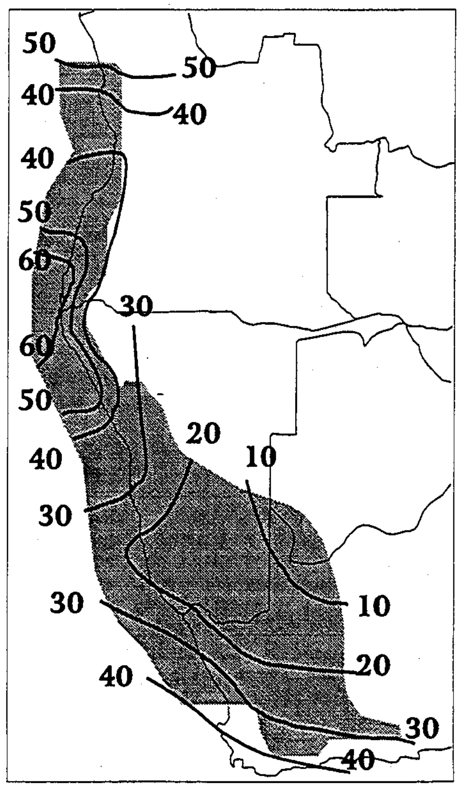



**Figure 4-11. July Percent Frequencies of Ceilings.**

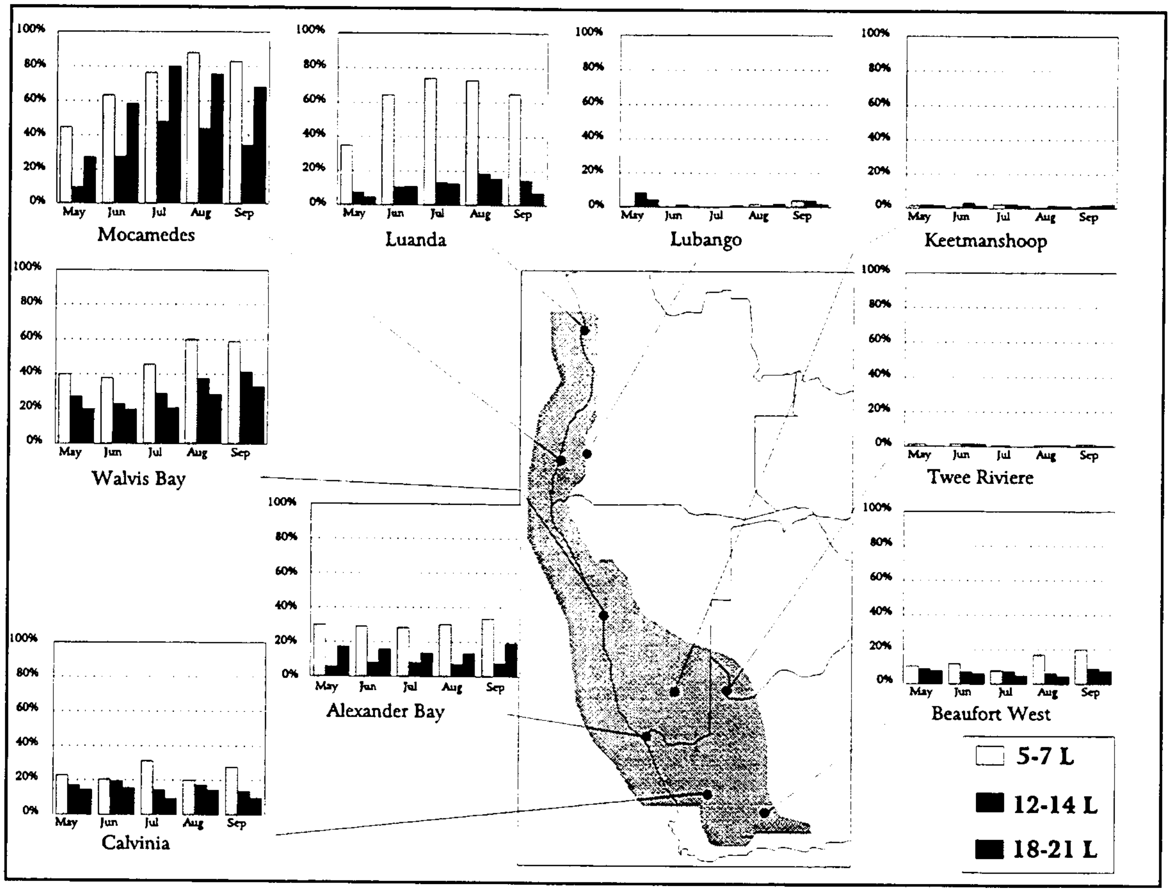



**Figure 4-12. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet.**

**Visibility.** Morning sea fog causes most low visibilities on the coast. The fog is usually less than 450 meters deep, but it can be as thick as 900 meters when associated with disturbances. Its maximum landward penetration is usually 45-55 km, but disturbance-associated onshore flow in the south can push sea fog to the escarpment and 150 km up the Orange River Valley.

Sea fog is more common than in the wet season along much of the coastline of Angola and Namibia (see Figure 4-13, next page). Frequencies are most variable across Angola. Fog is most common in northern Angola late in the dry season, but earlier in the south.

North of about 13° S, fog reduces visibilities to between 1.5 and 15 km, averaging 10 km. Sea fog can cause visibilities along the entire coast south of 13° S to fall below 1,600 meters. Mean monthly frequencies range from less than 1 day (near much of the escarpment in the north and along sections of Angola's coast) to 10-15 days on most of Namibia's and South Africa's coasts.

Drizzle and mist rain make low sea-fog visibilities even worse. Radiation fog occasionally forms between the coast and the escarpment; depths are less than 160 meters. Barring disturbances, visibilities on the coast through about 8 km out to sea are at their best from around noon to sunset. Daytime reductions are usually due to haze. Beneath strong inversions, salt and dust haze can lower visibilities below 8 km. In Angola, salt haze and smoke can drop visibilities to between 3,200 and 4,800 meters.

Berg and buster winds are responsible for most duststorms and sandstorms. Berg winds also inhibit fog by pushing dry air from east to west. Strong winds can cause suspended dust and duststorms nearly anywhere on the coast, especially near the Quicksand Dunes. Sandstorms may also occur near dunes. Visibilities can fall below 1,200 meters in dust and sand. Coastal deserts see solar heating interfering with visibilities due to "shimmering" air.

On the coast, visibilities below 1,600 meters are rare in the afternoon, except along Namibia's coast, where they occur 15% of the time; these low visibilities are most common on early winter mornings (30% of the time.) Figure 4-13 (next page) shows frequencies of visibilities below 4,800 meters.

Low visibilities are rare across the interior, but radiation fog forms near interior rivers on cool nights; hoar frost can result. Radiation fog is important since it can affect places suddenly and unexpectedly; depths are less than 160 meters and it burns off quickly after sunrise.

Disturbance- associated fog occasionally moves in through the western Orange River Valley, but fog occurs on less than 5 mornings a month over most of the interior. Daytime haze occurs less than 5 days a month in most areas, but it can reach a mid-wet season maximum of about 20 days a month along Angola's escarpment. Visibilities below 4,800 meters are very rare (Figure 4-13). Raised dust reduces visibilities on less than 3 days a month; visibilities can fall below 1,200 meters in duststorms. Heat-induced mirages interfere with visibilities.

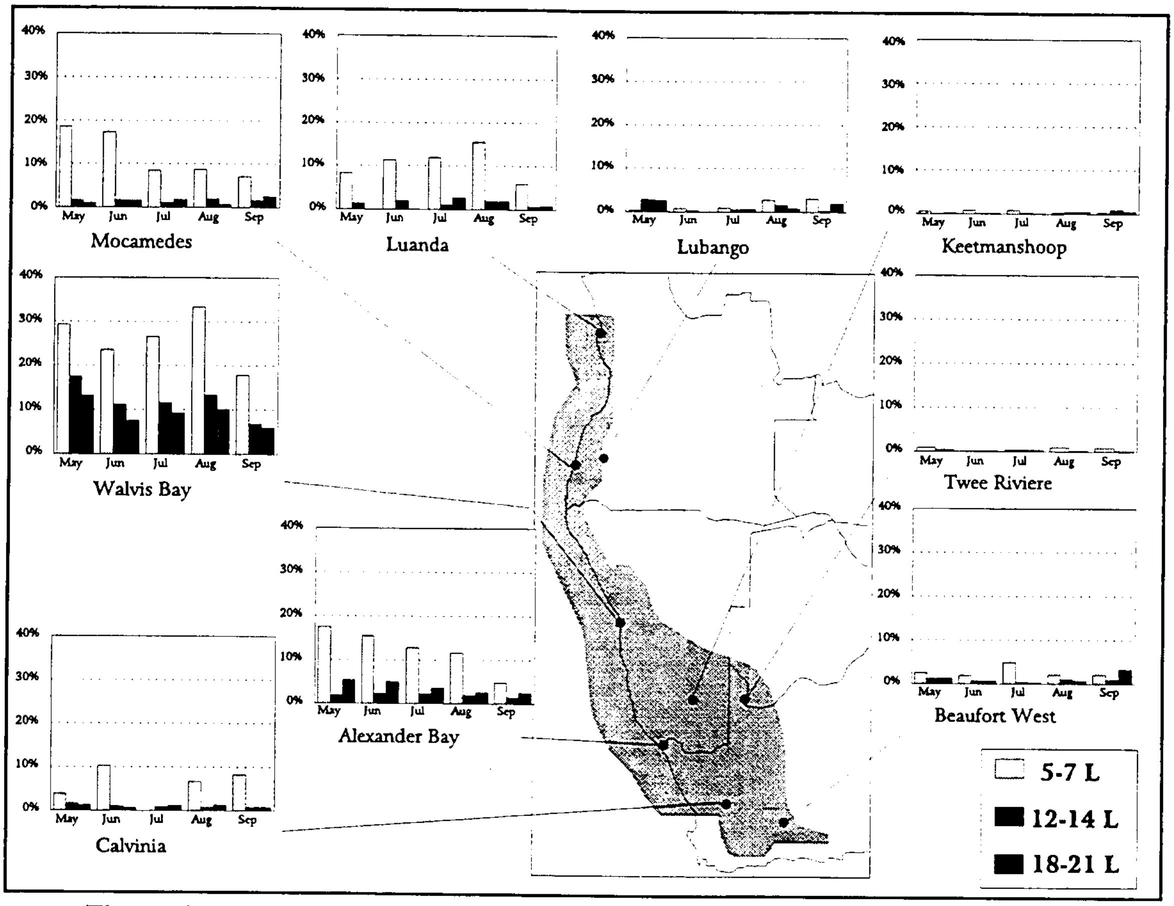



**Figure 4-13. Dry Season Percent Frequencies of Visibilities Below 4,800 Meters.**

**Winds.** The trades cause southeasterly-to-southerly winds to prevail at sea; the maximum trade-wind band moves about 5° north of its wet-season position. Local circulations, especially sea breezes, cause the trade-wind flow to vary over the coast. Sea-breeze depths are usually less than 500 meters. South of 27-28° S, temperate disturbances displace the trades and make winds more variable. Winds may be enhanced or dampened by local sea breezes, depending on the direction of synoptic flow. Flow north of the disturbances makes northwesterlies common south of the Orange River, where they occur 30-50% of the time, compared to 5-15% of the time in the wet season. Berg winds occur on some dry-season mornings, but sea breezes usually overcome them and cause winds to back to southwesterly by afternoon.

The daily cycle on the coast is similar to that in the wet season, but it happens less frequently and varies more from day-to-day since berg winds and temperate disturbances are more common in the dry season. The coast's morning winds are most often calm to weak; afternoon speeds are usually 10-25 knots.

Near the escarpment, easterlies develop more often than in the wet season, peaking on late dry-season mornings when they occur about a third of the time. Wind directions are more variable inland, where they are most often northerly or northeasterly. Interior winds on nights and mornings are usually calm, with occasional light slope winds. Weak mountain-valley breezes form. Mean afternoon wind speeds in the interior are mostly 10-15 knots, but stronger in the south and where flow is channeled through passes.

Coastal winds are strongest where sea breezes are enhanced by onshore synoptic flow, such as ahead of late-season fronts and during the very brief "busters" that occur north of coastal lows. Buster winds average 20-30 knots, gusting to around 50 knots. These, along with berg winds, cause the region's highest winds on the coasts of southern Namibia and South Africa. The season's strongest winds (near the escarpment of Namibia and South Africa) are mostly southerly or northwesterly because of channeling. Occasionally, southwesterly winds follow cold fronts, the primary cause of strong winds in the interior, where extreme speeds range from near 30 knots in the north to near 40 knots in the south.

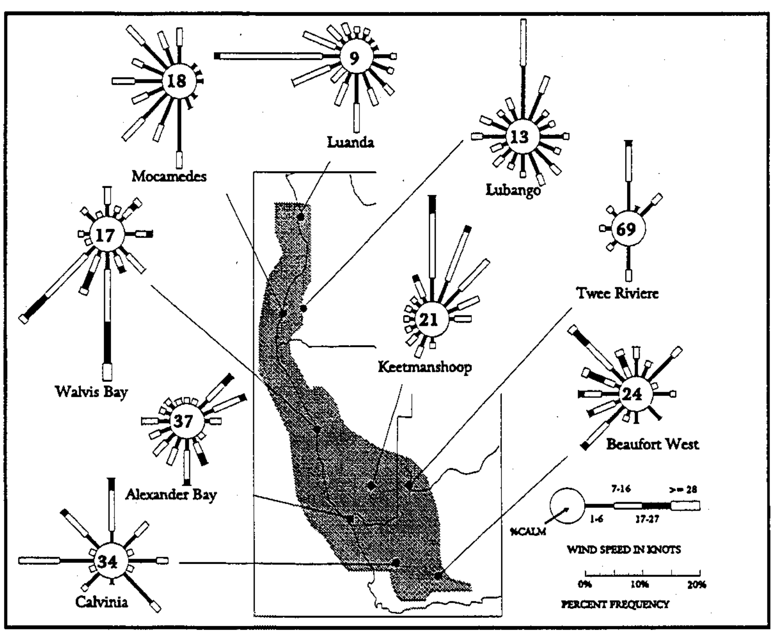



**Figure 4-14. July Surface Wind Roses.**

**Winds aloft** are southeasterly in the north, becoming variable to easterly above the trade-wind inversion. Low-level winds become increasingly variable to the south.

Above 300-600 meters, winds aloft are typically westerly-to-northwesterly with speeds less than 20 knots through 900 meters.

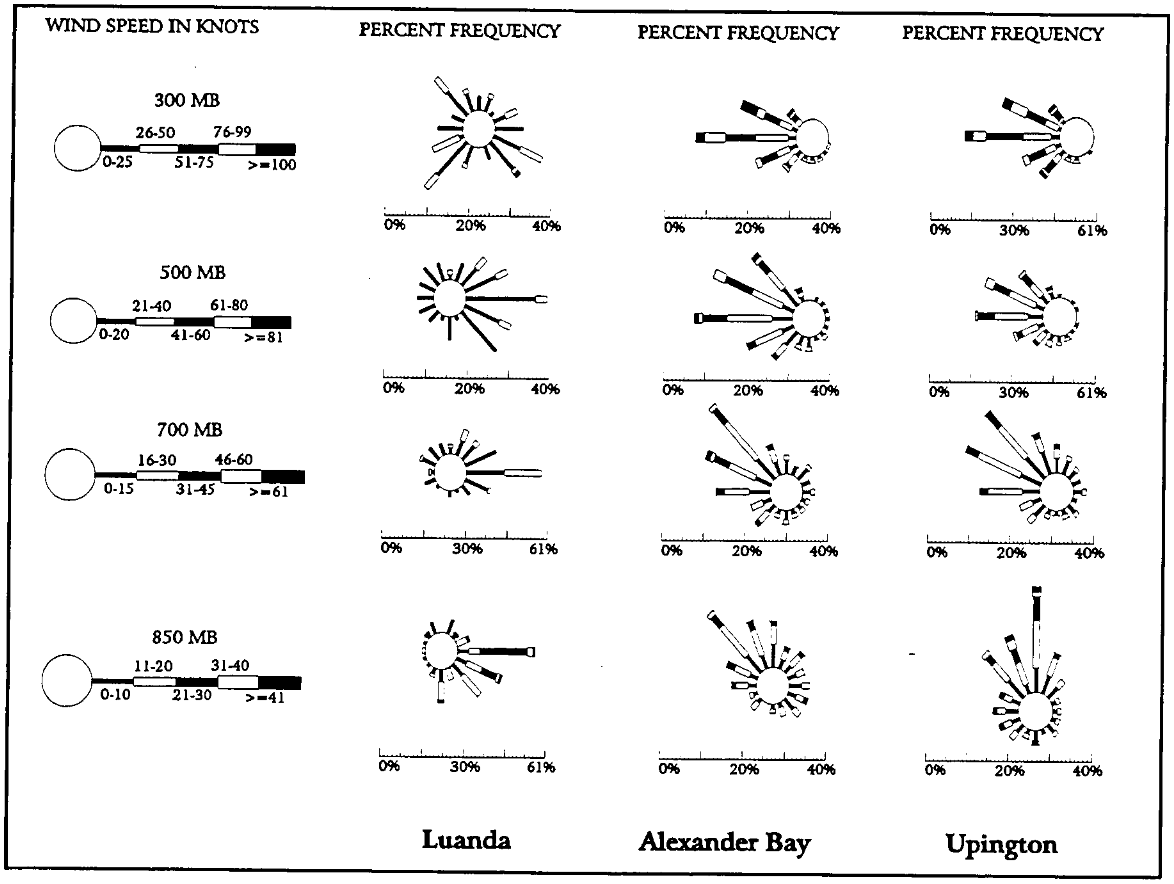



**Figure 4-15. July Upper-Air Wind Roses.**

**Precipitation.** Little precipitation falls on the Southwest Coast during the dry season. This is true even in Angola, where monthly amounts in the late wet season (75-150 mm) drop to 25 mm or less in May (see Figure 4-16). Except for May in Angola, amounts are less than 13 mm. The southern coast and southwestern mountains receive most of their precipitation in the dry season because more frequent temperate disturbances enhance rainfall.

Precipitation is most frequent in Angola (Figure 4-17, next page), but even here it is usually only occasional light drizzle.

Showery precipitation is rare; drizzle falls, mostly just after sunrise. Coastal precipitation south of 27-28° S falls most often as drizzle during onshore northwesterly flow associated with temperate disturbances or coastal lows. Showery precipitation can fall near temperate disturbances, forming along and immediately behind cold fronts. A single cold front is known to bring 50 mm of precipitation to the Orange River valley; most of this falls within 55-80 km of the shoreline and on windward mountainsides.

Light snow and freezing precipitation occasionally falls in the region's high elevations behind cold fronts or with cut-off lows; accumulations are insignificant and they melt quickly.

Interior precipitation falls with disturbances, generally as brief rainshowers. Monthly frequencies range from less than 1 day a month north to about 3 a month south.

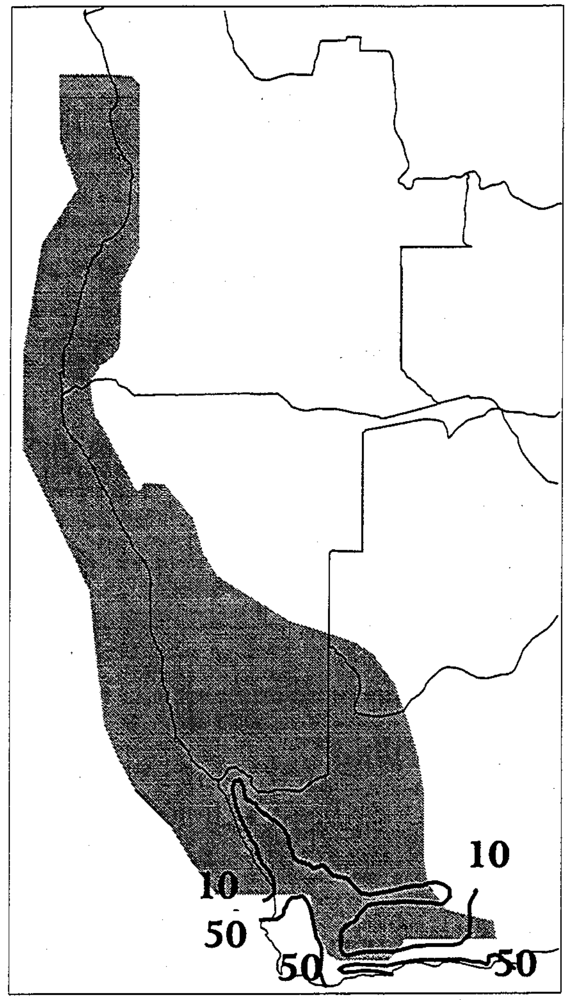



Figure 4-16. July Mean Precipitation (mm.)

**Thunderstorms.** Dry-season thunderstorms are very rare across most of the region. They generally form near temperate disturbances in the south, but are also known to form in Angola. Small hail is possible in the south.

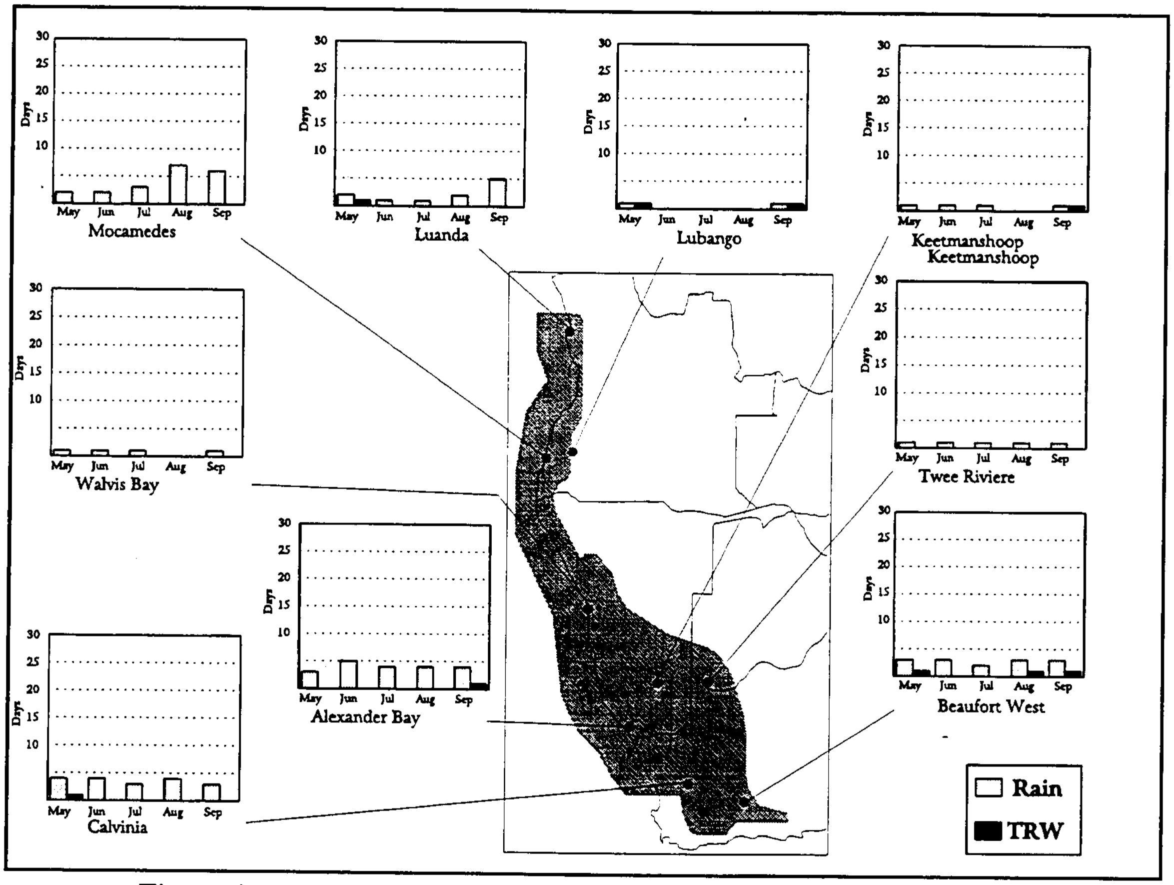



**Figure 4-17. Dry-Season Mean Monthly Rain and Thunderstorm Days.**

**Temperatures.** Day-to-day temperatures are more variable than in the wet season, because of frequent berg winds and temperate disturbances that interrupt moderating oceanic effects. Berg winds, occurring on 5-10 days a month in Namibia and South Africa, drive mean monthly maximums in some areas to about 3 degrees higher than they would be otherwise. Extreme coastal highs are the result of bergs and are consequently higher than wet-season extremes at a few locations. Extreme highs are mostly 25-35° C on the Angola coast and 30-40° C on the coasts of Namibia and South Africa where bergs have the most effect; 48° C has been recorded.

Whether bergs occur or not, the warmest daily coastal temperatures usually occur before the sea breeze sets in, which is usually in the morning on the coast, but later with increased distance inland. Daily highs on the coast vary from 15-25° C in Namibia and South Africa to 20-30° C in Angola (Figure 4-18). Sea breezes may be blocked from some valleys and depressions, allowing temperature characteristics to resemble those in the interior, where temperatures peak in mid-afternoon. Mean highs in the interior range from 15-20° C south to 20-25° C north. Extreme interior highs range from 25-30° C in mid-season to around 40° C late in the season.

Throughout the dry season, oceanic effects cause nocturnal temperatures on the coast to average only about 5 degrees lower than in the wet season. Temperatures fall much more freely beyond about 30 km inland, where less frequent fog and stratus allow stronger radiational cooling.

Temperatures are more diurnally variable in the interior where the air is much drier, allowing lows in the mid-dry season to average nearly 20 degrees lower than wet-season lows. Extreme mid-season lows on the coast range from about freezing in the south, to about 15°C in the north. Freezing temperatures in the interior are possible during any month. Extreme lows can fall to near -10° C.

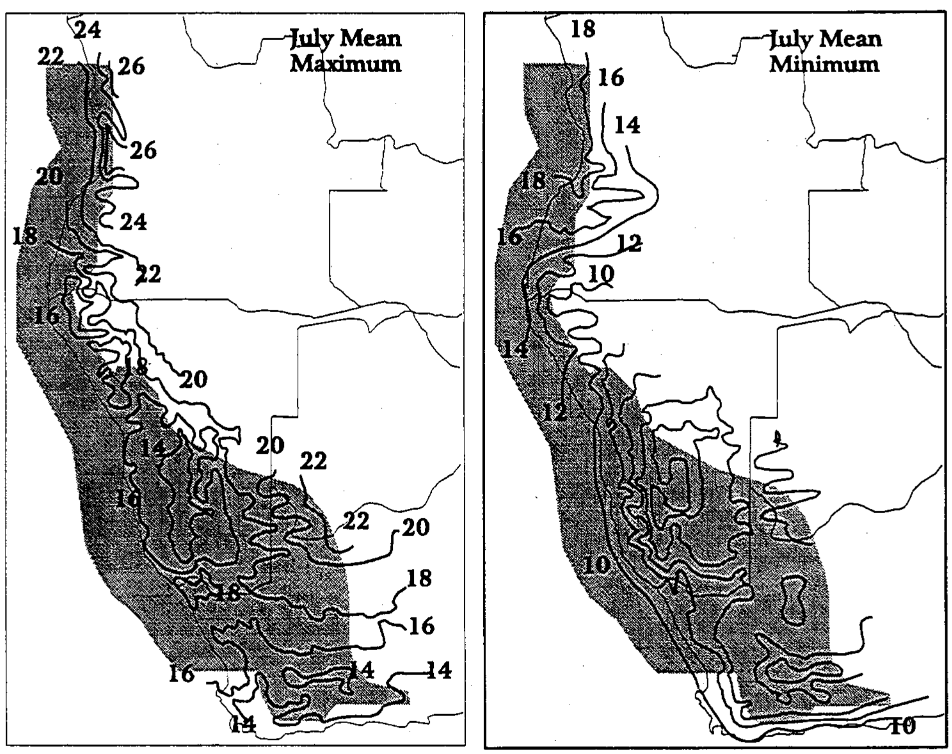



**Figure 4-18. July Mean Maximum and Minimum Temperatures.**

**Other Hazards.** All factors (fog, clouds, and dust) combine to lower inflight morning and early afternoon visibilities on the coast to below 15 km. Inflight visibilities are below 8 km on 20-30% of late mornings and early afternoons. Suspended dust can reduce inflight visibilities to below 1,600 meters throughout the region.

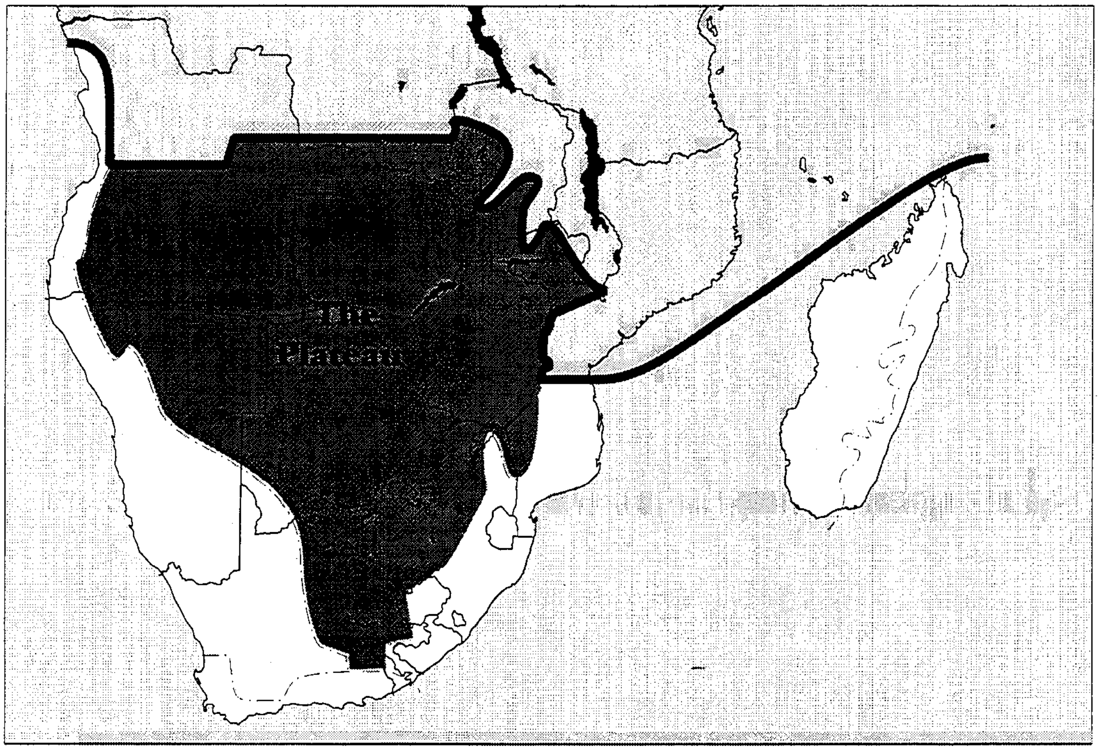
Sandstorms in the Quicksand Dunes can block roads and railways. Dust-devils occasionally form in the afternoon.

Large breaking sea swells cause difficult ship navigation near shores, especially in the south.

# Chapter 5

## THE PLATEAU

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for the Plateau of Southern Africa, as shown below.



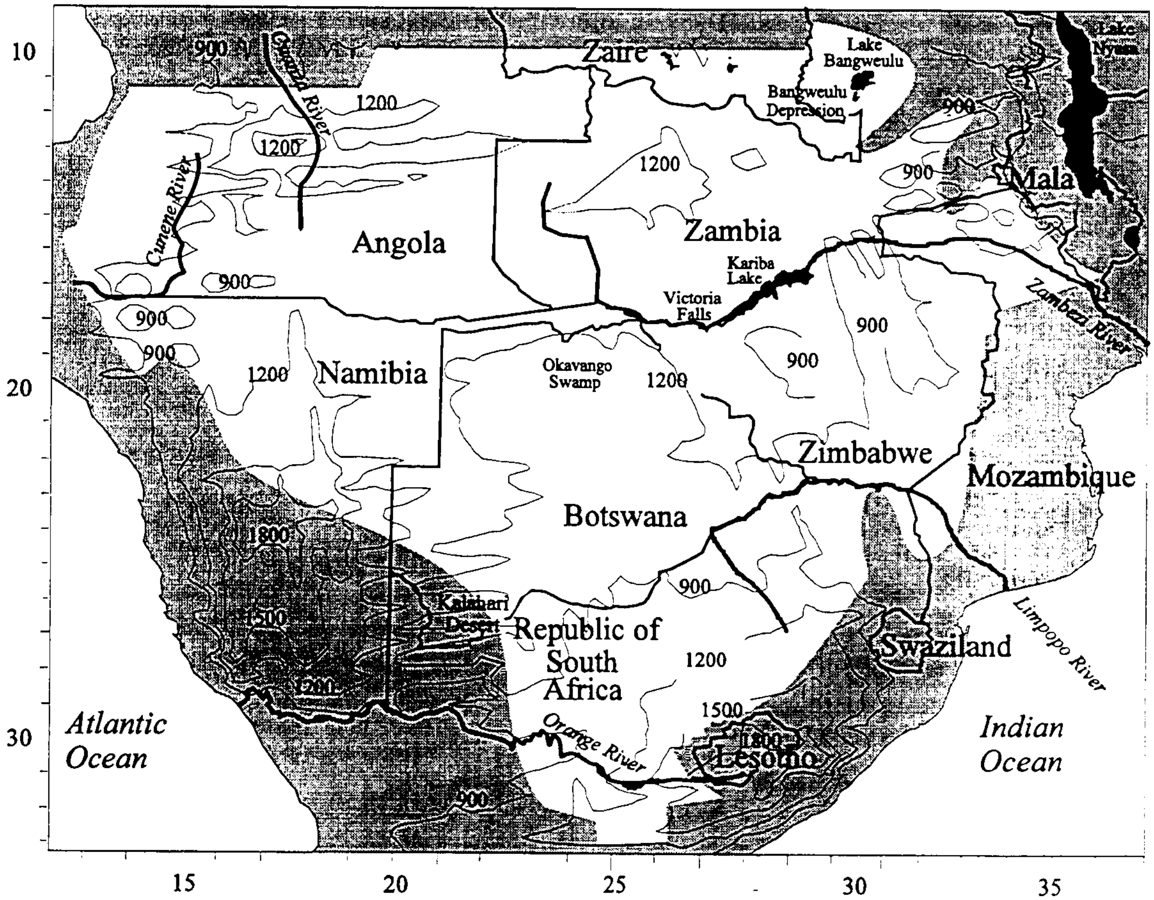



**Figure 5-1. The Plateau of Southern Africa.**

**Boundaries.** As shown above, the region known as the Plateau of Southern Africa includes all of Zimbabwe, nearly all of Botswana, and portions of Angola, Zambia, Zaire, Mozambique, Namibia, and the Republic of South Africa (hereinafter referred to as "South Africa"). The northern boundary of the region is the Congo (Zaire) River basin. The western edge is formed by the mountain range that separates the drier interior from the ocean boundary layer. The eastern boundary is the ridgeline of the mountains that separate the Plateau from the coastal areas that are influenced by the Indian Ocean. The southern boundary is the approximate dividing line between regions governed by a wet/dry regime, and those within a temperate zone.

**Major Terrain Features.** Mountains almost entirely encircle this flat to gently rolling Plateau region. The surface of the Plateau varies from rocky to sand-covered, with sand-dune crests reaching up to 90 meters above the plain. Its high elevation is the most significant physical feature of the region; elevations are generally above 900 meters. In most of southern Zaire, elevations are above 1,500 meters. Angola consists of broad-based tablelands that range in altitude from 900 to 2,100 meters . The Angolan highlands contain a few peaks above 2,500 meters. High terrain continues into northeastern Namibia, where massive granite massifs rise from the plains.

# PLATEAU GEOGRAPHY

**General.** Northern Botswana is a gently undulating plateau with an average elevation of 900 meters; it contains the 10.4-square km Okavango Swamp in the north. Part of the Kalahari Desert is in southwestern Botswana and part in South Africa; plateau elevations in South Africa average 1,200 meters.

A 644-km-wide ridge runs from the southwest to the northeast across Zimbabwe, with elevations of about 1,200 meters. It rises to 2,590 meters at Mount Inyangani, the country's highest point.

Zambia is also mainly a plateau with some isolated low mountain ranges. Most elevations range from 900 to 1,500 meters, but the Mufinga hills in the northeast exceed 2,100 meters . Another important feature in Zambia is the Bangweulu Depression located in the northeast part of the country. With over 10.4 square km, it is one of the largest inland swamps in the world.

**Rivers and Drainage Systems.** There are three major rivers in Zambia: the Chambehi and Luapula in the north, and the Zambezi in the south. The northern rivers begin at Lake Bangweulu and drain into the Congo River. The Zambezi River originates in the Angolan Highlands and bisects the Plateau. The Cabora Bassa and Kariba Dams have created two man-made lakes on the Zambezi River. There are many areas of low, swampy ground along the Zambezi river and its numerous tributaries. These depressions, or pans, vary in size from about a hundred square meters to hundreds of square kilometers. They have normally dropped below the surface of the surrounding plain by a few to several hundred meters. The larger depressions are partially filled with water much of the year. Similar swampy areas are found in eastern Angola, the lower elevations of northern Botswana, northern Zambia, and Namibia. Many of these are subject to seasonal flooding.

Rivers from eastern Angola flow through the southeastern portion of the region into the Okavango swamps of Botswana. The Okavango and Orange Rivers are the major perennial waterways in Namibia. The Okavango also provides the main drainage system for most of Botswana. The Limpopo River and its tributaries drain the eastern portions. The main river in Zimbabwe is the Zambezi. The Limpopo also contributes significantly to drainage in Zimbabwe.

**Vegetation.** Angola's vegetation consists mostly of savanna, but dense forests are found near the Cabinda border. Thorn scrubs grow in the south. Wooded savanna with small leguminous trees prevail in the plateaus of Zambia, and the mopani tree flourishes in the low regions. Wooded savanna is also found in central and eastern Namibia. In Botswana, dry scrub and tree savanna are present, but there is only sparse thorn bush in the Kalahari region. Zimbabwe is predominantly tropical grassland, but trees are spread throughout the region due to the country's wet summers; the only true forests are located along its eastern border.

# MAJOR CLIMATIC CONTROLS OF THE PLATEAU

**South Atlantic (St Helena) High.** The mean surface position of this subtropical high in July is 26° S, 12° W. Its eastern end remains relatively fixed along the southwest coast of Africa; as a result, most frontal systems crossing the South Atlantic do not penetrate the African interior.

**South Indian Ocean (Mascarene) High.** This subtropical high's mean surface position in July is 29° S, 65° E. It frequently extends westward over Africa, stabilizing the weather by enhancing the South African High.

**South African High.** This high is a continuation over land of the subtropical belt of high pressure between the South Atlantic and South Indian Ocean Highs. It is often an extension of the South Indian Ocean High and is strongest during the winter dry season. The South African High is one of the reasons for the semiarid conditions on the Plateau.

**The Near Equatorial Trough (NET).** The seasonal location and movement of the NET is responsible for much of the thunderstorm activity during the summer rainy season, as well as for the lack of this activity in the dry season. See Chapter 2 for a detailed description of the NET.

**The Congo Air Boundary (CAB).** This convergence zone between airflow from the South Atlantic High and the Indian Ocean High produces the summer precipitation maximum seen on the Plateau. The CAB is discussed in detail in Chapter 2.

## SPECIAL CLIMATIC FEATURES OF THE PLATEAU

**Terrain and Air Masses.** The Cuanza River Valley is the only entrance to the interior for maritime tropical air along the west coast. To the east, the coastal mountains of Mozambique and South Africa do not completely block onshore flow. However, their orographic lift and resultant precipitation almost completely transform maritime tropical air masses to drier continental tropical air before they reach the heart of the Plateau. Additionally, the high elevations of the Plateau combine with low humidities to cause much lower nocturnal temperatures than would be expected in these latitudes.

**General Weather.** During the wet season, the South Atlantic High is located slightly south of its dry-season position and the Indian Ocean High is centered well east of its dry-season position (see Chapter 2). The Zambian Low is at its southernmost point, near the center of the Plateau. Most of the air arriving from the northeast has an overwater trajectory around the periphery of the South Atlantic high. This moist, unstable air produces cloudiness and thunderstorms over the area.

The most typical wet-season pattern is a trough extending poleward from the low-level subtropical low over the continent. This trough penetrates into southern Africa and may remain quasi-stationary over the western interior while low-level maritime high pressure cells move around the coast. The subtropical trough over the interior frequently persists for a week, and occasionally remains in place for up to 2 weeks. Warm moist air from the tropical Indian Ocean penetrates into the interior when this synoptic pattern dominates; such flow is often associated with high instability and the resulting thunderstorms over the Plateau.

Occasionally, a tropical low center develops in the trough over central Africa. Interaction between this weather system and temperate troughs passing south of the continent leads to the development of cloud bands and convective rain showers over the southern interior.

Wave disturbances in the westerlies occasionally develop into cut-off low centers over the southwestern tip of the continent. The flow on the east side of these systems brings warm moist tropical air over the interior. Orographic lifting and convergence of this cyclonic flow results in heavy rain showers over most of the area. Summer cut-off lows over South Africa last for about 2 or 3 days (Hayward and Steyn, 1967).

Anticyclonic flow (counter-clockwise in the southern hemisphere) over the Southern African interior occurs occasionally during the wet season. It produces hot, dry weather and drought conditions over most of the region, especially in Namibia, Botswana, and South Africa. Cloud development is suppressed, along with thunderstorm development. The southeasterly flow brings rain to the northeastern part of South Africa, but seldom brings precipitation to the Plateau. Cyclonic flow over Angola brings isolated showers to northern Botswana.

In addition to the day-to-day control exercised by the pressure systems farther south, the character of the rainy season is also set by the behavior of the NET, which is at its southernmost location during the wet season (sometimes as far south as the Limpopo River Valley). As a result, thunderstorms occur frequently, especially over the northeastern Plateau. Congo air arrives in Zambia nearly saturated after gaining moisture by traveling over the Atlantic and the Congo rain forests, and after several hundred meters of orographic lifting. It is the wettest air mass to affect this area. Northeast monsoon air is usually already modified by the time it enters Zambia; its moistness depends on whether it tracked over the East African land mass or over the Indian Ocean. The southeast trades contain moisture only in the lowest layers; they are regarded as *dry* air masses, bringing fair weather and limited shower activity.

**Sky Cover.** Even though the wet season is the season of maximum cloudiness, sunshine is still abundant even during the cloudiest months. The greatest cloudiness is in the eastern and northern parts of the Plateau (see Figure 5-2). The increase in cloudiness between seasons is most pronounced in the north, where mean monthly cloud cover is about 50 to 60% greater than in the dry season. North of 15° S, the air is much more moist than over the rest of the Plateau, and cloud cover is more extensive and persistent.

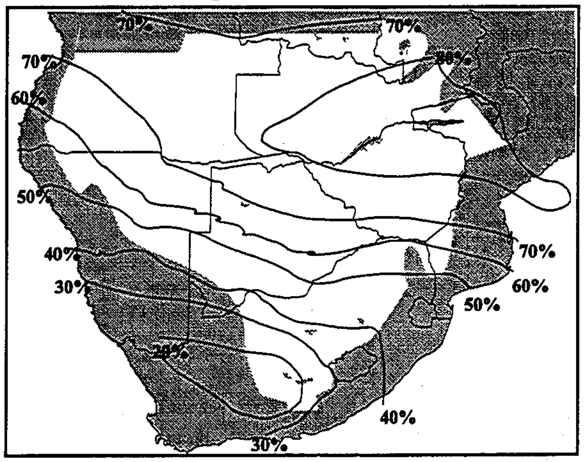



**Figure 5-2. January Percent Frequencies of Ceilings.**

A diurnal pattern of cloud development and dissipation is common during the wet season. Mornings often begin with altostratus and patchy rain, with or without stratus. Cumulus clouds start forming as soon as there are any gaps in the mid-level clouds. As the middle clouds break and disperse, cumulus grows rapidly into cumulonimbus. Showers and thunderstorms are most numerous during the afternoon, but may last into the night. The morning altostratus is reestablished by the dissipation of afternoon and evening thunderstorms.

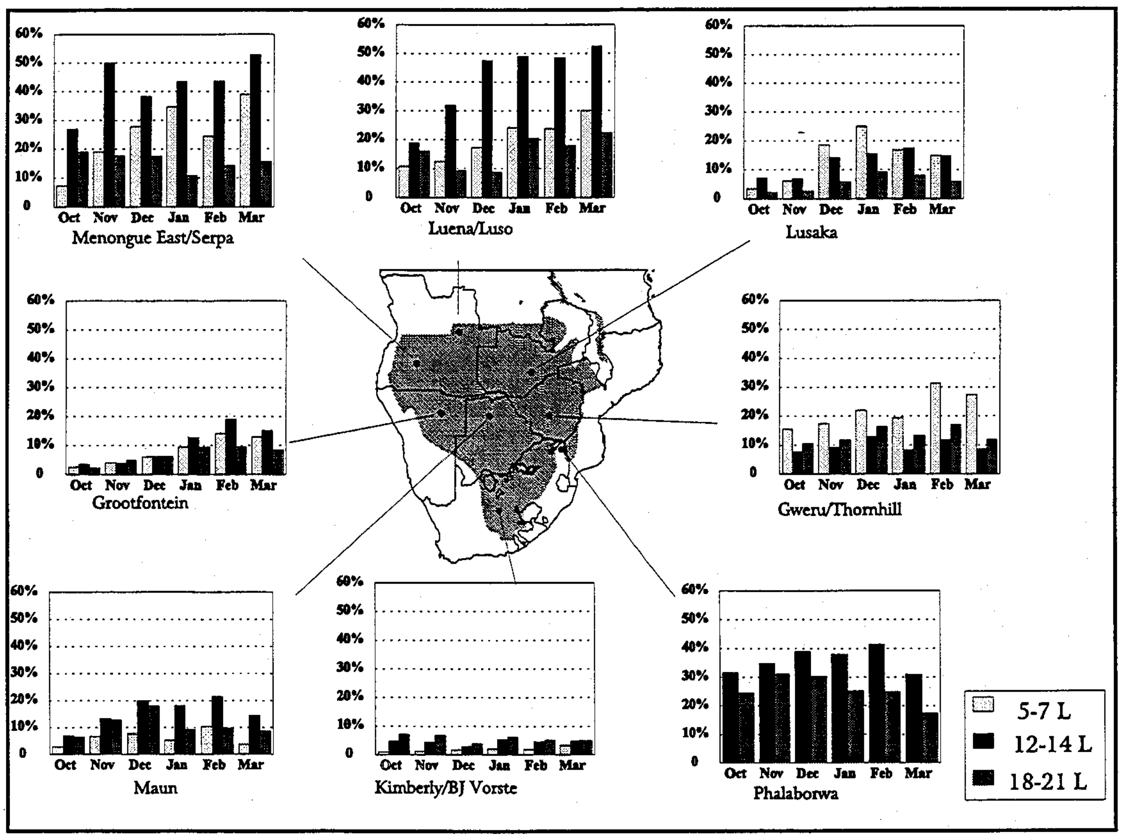



**Figure 5-3. Wet-Season Percent Frequencies of Ceilings Below 3,000 Feet.**

**Visibility.** Visibility is usually better during the wet season than the dry; it is above 4,800 meters 95 to 100% of the time (see Figure 5-4). Visibility can be reduced at times by heavy rain or by dust raised during squalls or strong winds.

Duststorms and sandstorms are common across the Kalahari; railway lines have been blocked by drifts of sand 3 to 4 meters deep. Winds from nearby thunderstorms can lower visibility to near zero. Dust-devils are common in the interior on hot days.

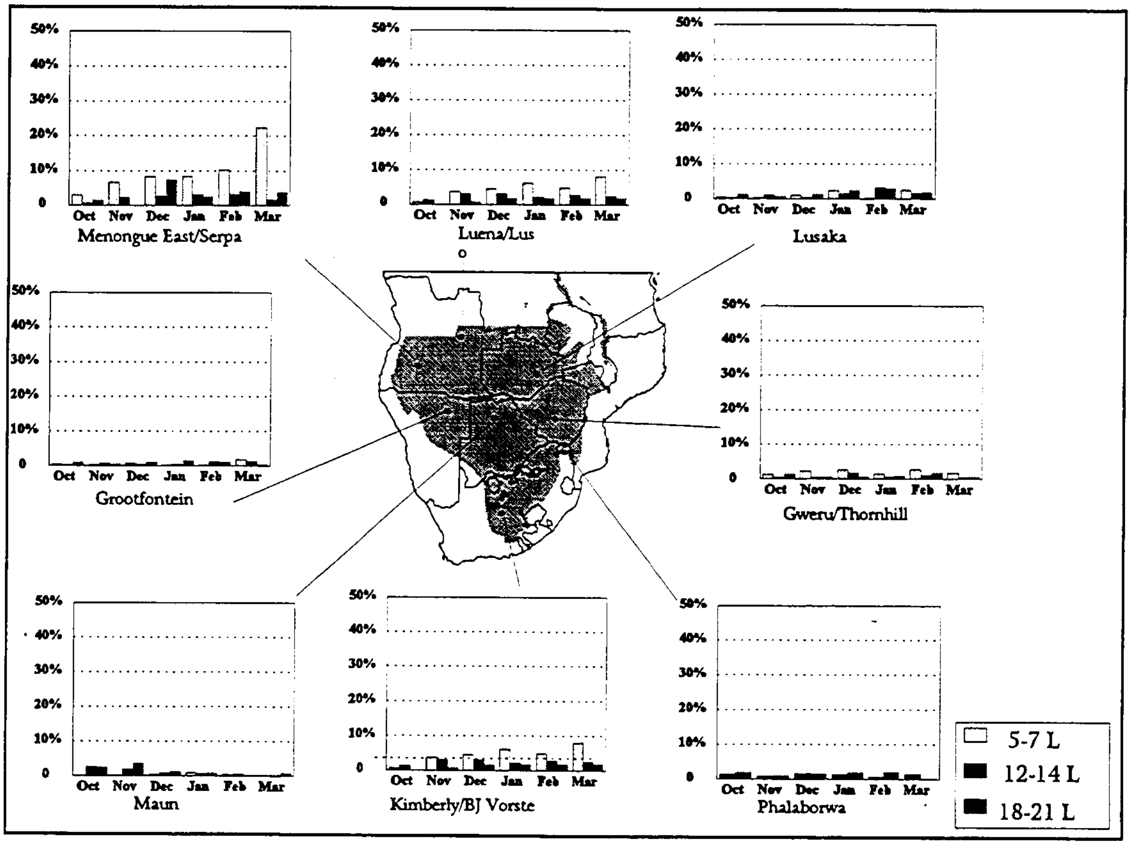



Figure 5-4. Wet-Season Percent Frequencies of Visibilities Below 4,800 Meters.

**Winds.** The Plateau's winds are largely affected by the position and movement of the high-pressure systems over the South Atlantic and Indian Oceans, as well as by the Congo Air Boundary. Local effects also contribute. Although the region lies within the southeast trade-wind belt, trade winds are not very pronounced due to the modifying effects of local topography. Surface winds are mainly from the east and south, but variable in the morning.

Mean wind speeds are normally between 3 and 13 knots during the afternoon. Although winds are stronger during the wet season than in the dry season, speeds greater than 27 knots are rare except with thunderstorm gusts. Winds on the northeast Plateau are from the northeast and east 75% of the time, with little diurnal variation—see the Lusaka wind rose in Figure 5-5.

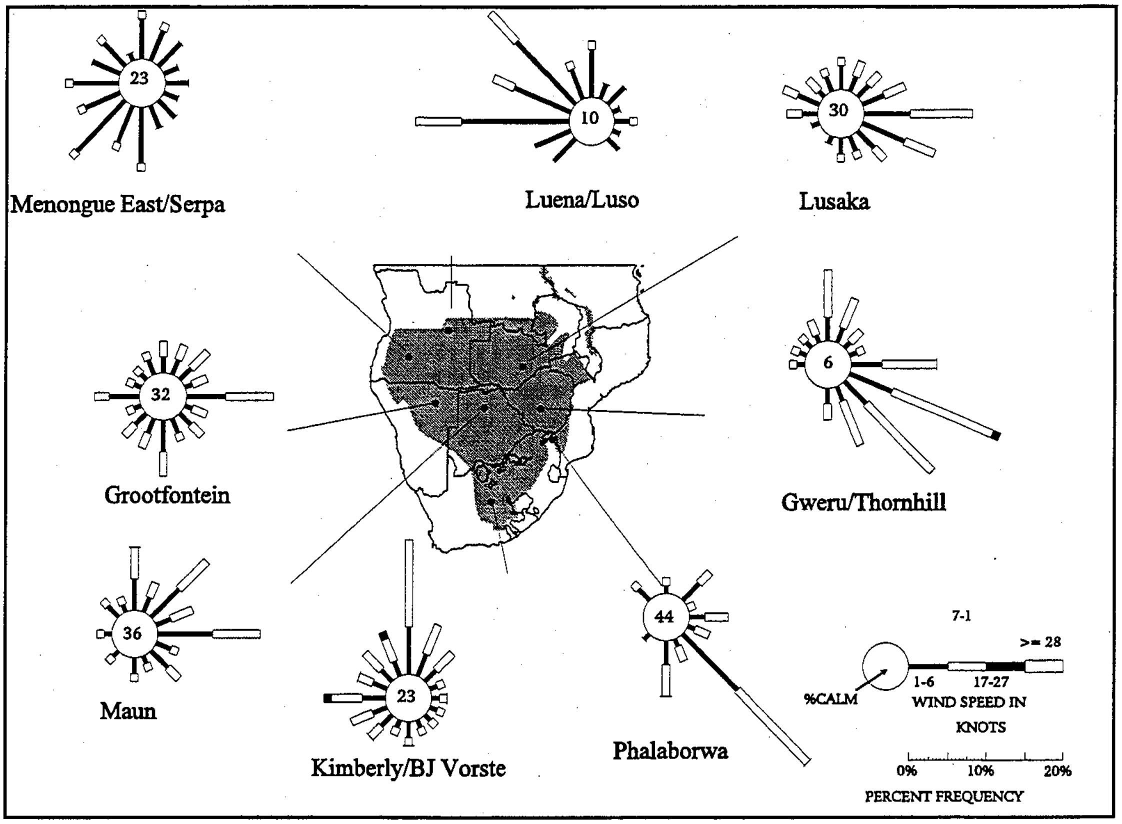



Figure 5-5. January Surface Wind Roses.

**Precipitation**. The beginning of the rainy season is not always clearly defined. As the southern hemisphere summer begins, sporadic afternoon thunderstorms gradually become more frequent as dew-point temperatures continue to rise. Increasing mid-level moisture soon becomes evident in the middle levels of the atmosphere. Extensive middle cloud becomes common once the rainy season has set in, particularly north of the NET. South of the NET, where the main flow is from the relatively dry southeast trades, rainfall tends to be more periodic; a few days of rain alternate with a few days of dry weather. These wet-dry spells are linked to the development and movement of pressure systems farther south. High pressure and southeast winds promote subsidence and decreased rainfall; falling pressure and closed lows or troughs add a northerly component to the winds and bring moist air farther south, increasing rainfall on the eastern Plateau.

Usually, 95% of the Plateau's annual rainfall falls in the wet season. Rainfall amounts show marked local variation, and there are likely to be large deviations from the mean value in any given year. Rainfall is greatest on the northeast part of the Plateau (see Figure 5-6), while low-lying areas such as the major river valleys generally receive the least. Rainfall is considerably greater over high ground and steep terrain. The heavy rainfall areas in the north appear to be related more to the availability of Congo air than to pronounced orographic features.

Indian Ocean cyclones have a widespread influence on the circulation over the northeast Plateau. When these cyclones lie between Mauritius and Madagascar, the supply of moist air is interrupted and periods of light showers or fine weather occur. On rare occasions these cyclones may move westward across Zimbabwe/Zambia and bring heavy rains to the area.

The position of the NET also influences annual rainfall patterns. In some years the mean position is at 10-12°S, in which case dry southeast trades cover most of the area to the south and rainfall is reduced. The more common position for the NET is about 15-17° S, but it occasionally moves as far south as the Limpopo Valley, bringing exceptional rains over Zimbabwe.

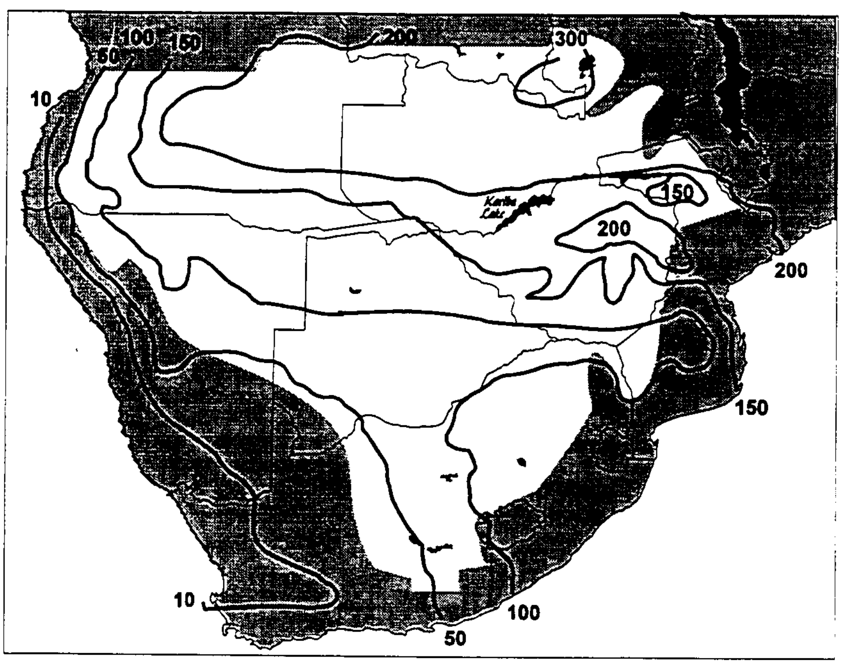



**Figure 5-6. January Mean Precipitation (mm).**

**Thunderstorms.** Thunderstorms are common during the wet season. By November, low-level easterlies are well established over Southern Africa, while well defined westerly flow is still present at 500 mb. The flow of cold, dry westerly air over the warm, moist easterlies creates a high degree of instability over the interior, leading to extensive thunderstorm development. As shown in Figure 5-7, the highest frequency of thunderstorms is in January and February when deep easterly flow is established over the interior. Thunderstorms are also associated with the seasonal migration of the NET and the northeast flow of moisture from the Indian Ocean.

Thunderstorms in November frequently produce hail, suggesting that these storms may be more severe than those occurring in later months (Schulze, 1972). Little information is available concerning the diurnal nature of hail occurrence, but there are indications that hail falls mostly between the hours of 1200 and 2200L (especially on the eastern Plateau—Schulze, 1967), with a pronounced maximum at about 1700-1800L.

Thunderstorm winds rarely exceed 35 knots, but speeds greater than 52 knots have been recorded. On rare occasions there are tornadoes; water spouts over swampy areas can also occur.

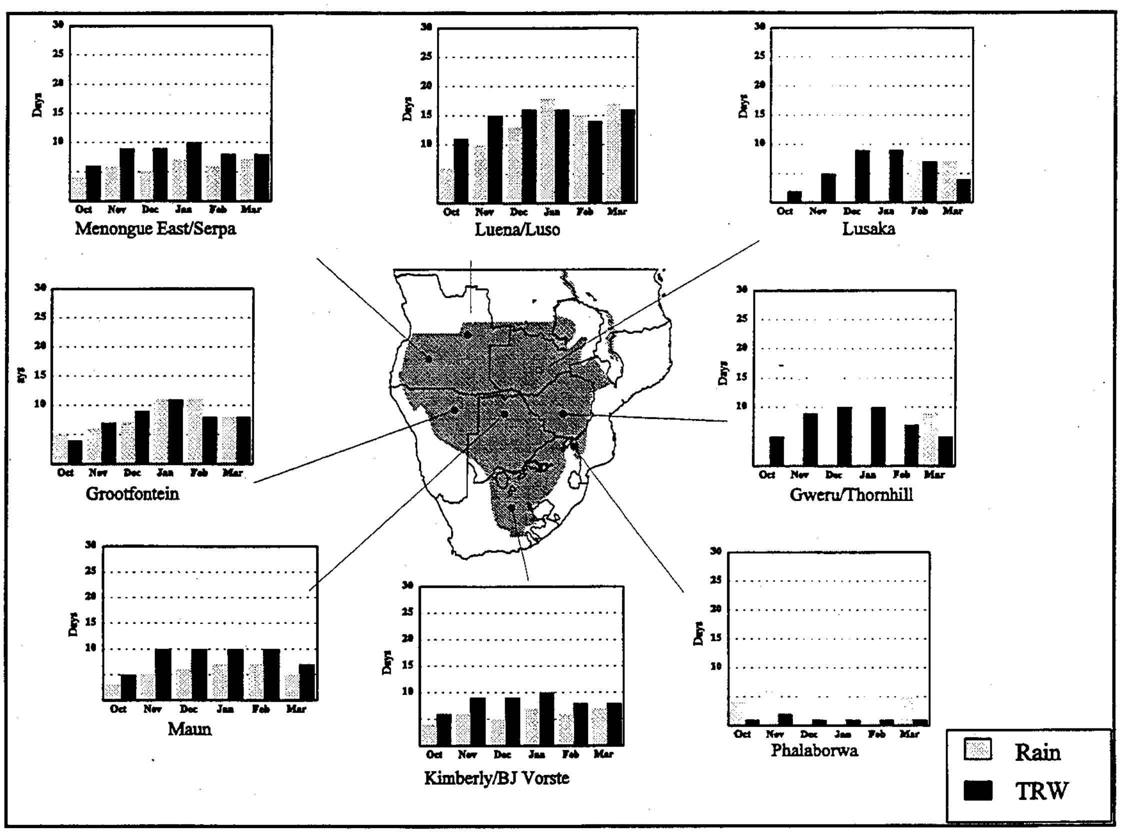



**Figure 5-7. Wet-Season Mean Monthly Rain and Thunderstorm Days.**

**Temperatures.** Generally speaking, the Plateau is warm to hot during the wet season (southern hemisphere summer), and cool during the dry season (southern hemisphere winter). Temperatures are modified by altitude and are lower on the Plateau than at lower levels; relative humidities are not generally high. In low-lying areas (mainly below 3,000 feet), temperatures are consistently high throughout the year; relative humidities are also higher. The seasonal range of temperature is much larger at high elevations than in the river valleys. The southeastern half of Zimbabwe enjoys periodic cool spells during occurrence of the "Guti" (see Chapter 2). Figures 5-8 and 5-9 show the mean high and low temperatures during the height of the wet season.

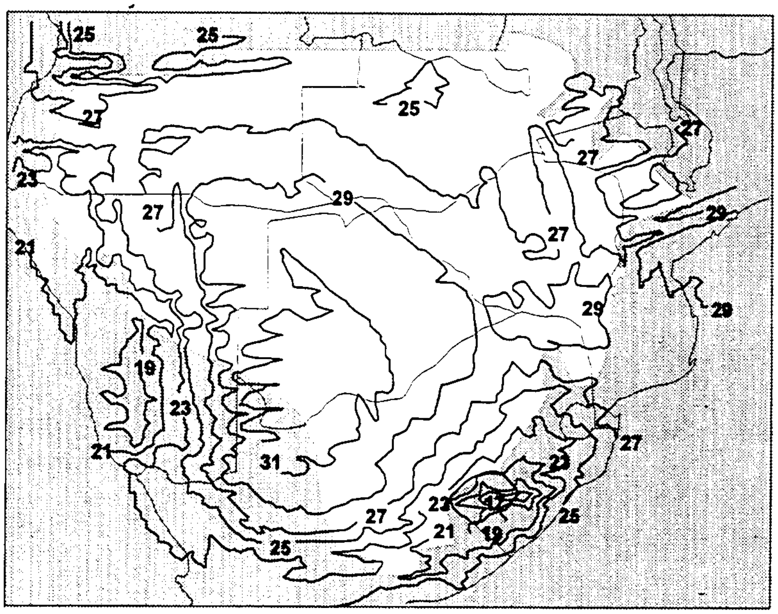


Figure 5-8. January Mean Maximum Temperatures.

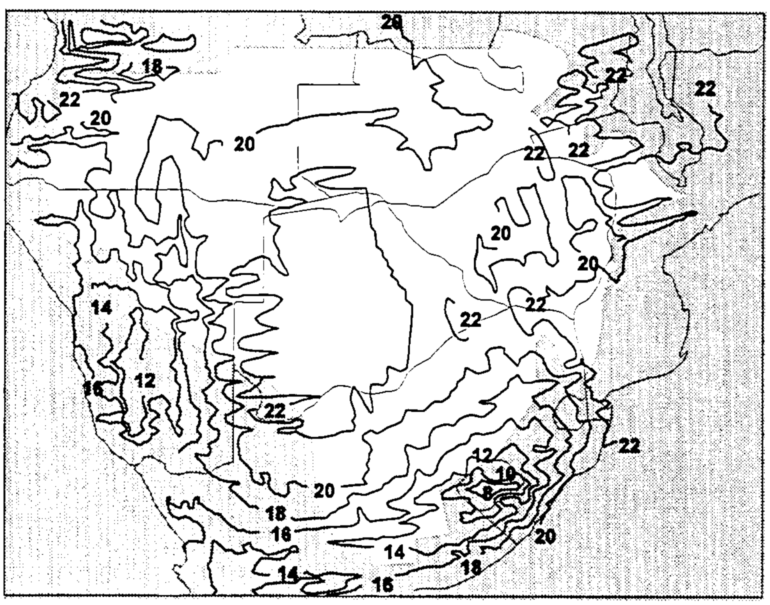


Figure 5-9. January Mean Minimum Temperatures.

**General Weather.** The thermal trough over southern Africa weakens as the NET makes its way to its northernmost position. It is now centered over northern Africa, with a weak thermal trough extending southward over the interior of the continent. High pressure dominates the Plateau (see the South African High discussion in Chapter 2).

The two high-pressure cells over the oceans are at their maximum intensities, usually connected by a ridge of high pressure. Sometimes there is a high-pressure center over South Africa. The resulting flow across the area is easterly. Although this air mass comes from the Indian Ocean, most of its moisture is depleted over the mountains of eastern and southern Africa. As a result, it is quite dry by the time it reaches the Plateau.

The dry season is cooler than the wet season. During the dry season the Plateau receives practically no rain. There are occasional frosts and, on many days, haze and smoke.

**Sky Cover.** Cloud development during the dry season is minimal due to subsidence and dry air (see Figures 5-10 and 5-11). The only exceptions are over lakes and rivers where some moisture is available. The clouds that do develop are primarily cumulus, with bases from 2,000 to 4,000 feet. Tops can exceed 10,000 feet.

Guti conditions (intervals of extensive low-level cloudiness, fog, and drizzle) can occur in either season. The Guti is caused when cool air advected into the Mozambique Channel rises over the higher elevations and becomes saturated; see Chapter 2 for a more detailed description.

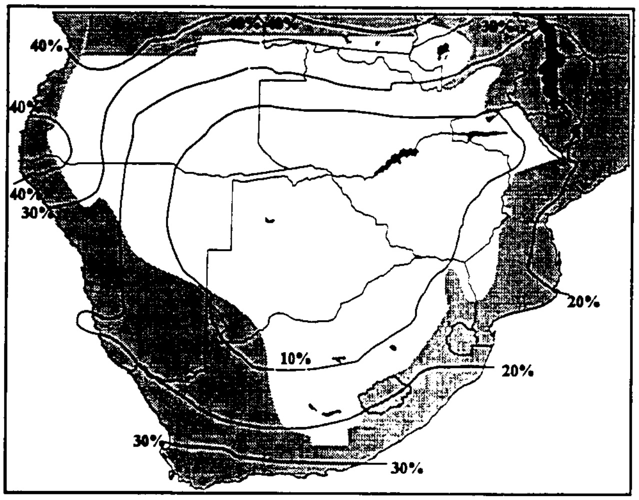



Figure 5-10. July Percent Frequency of Ceilings.

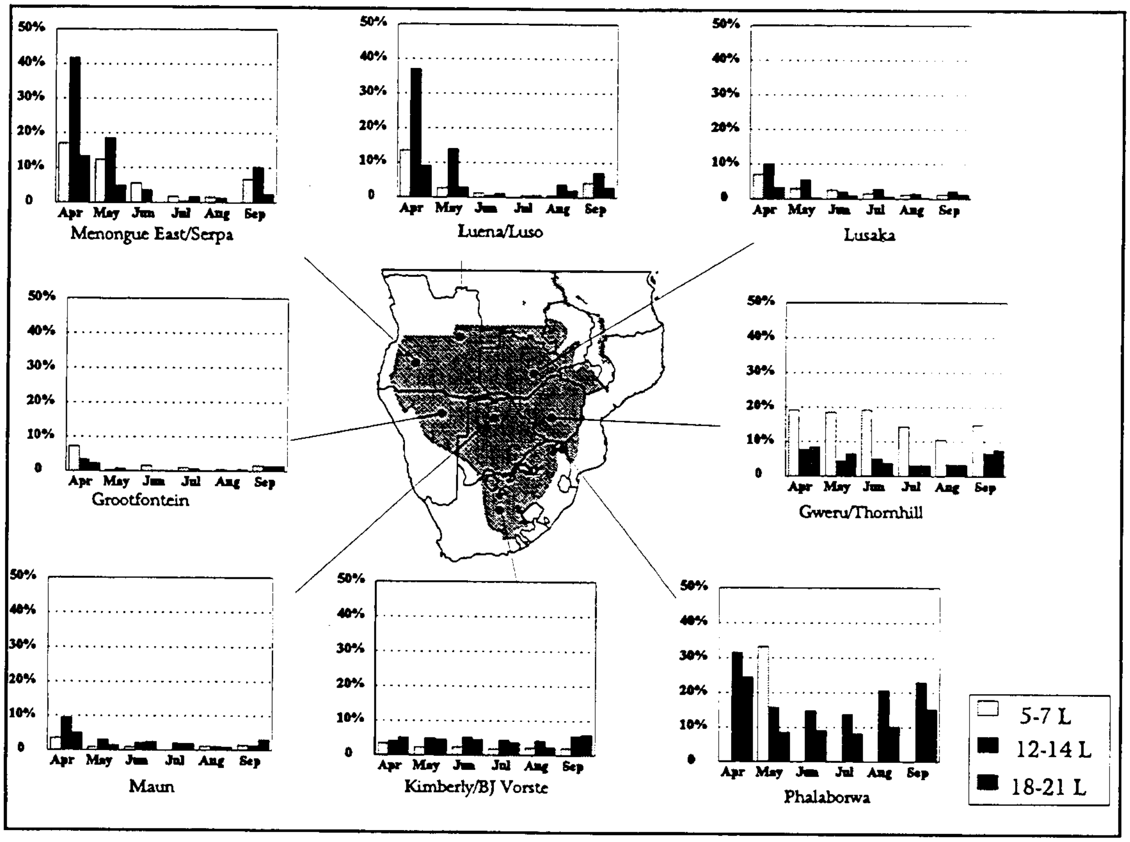



Figure 5-11. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet.

**Visibility.** The dry season is usually very dry and dusty, but visibility is restricted to less than 4,800 meters only about 2% of the time (see Figure 5-12). Visibility is often reduced by dust and haze, and occasionally by dust storms raised by squalls, or by smoke from grass fires.

The latter part of the season is the worst, with dust often raised by dry thunderstorms. Radiation fog occurs several times a month in some places, and is most common in April and early May. Fog forms during the early morning hours but usually dissipates by 0800L.

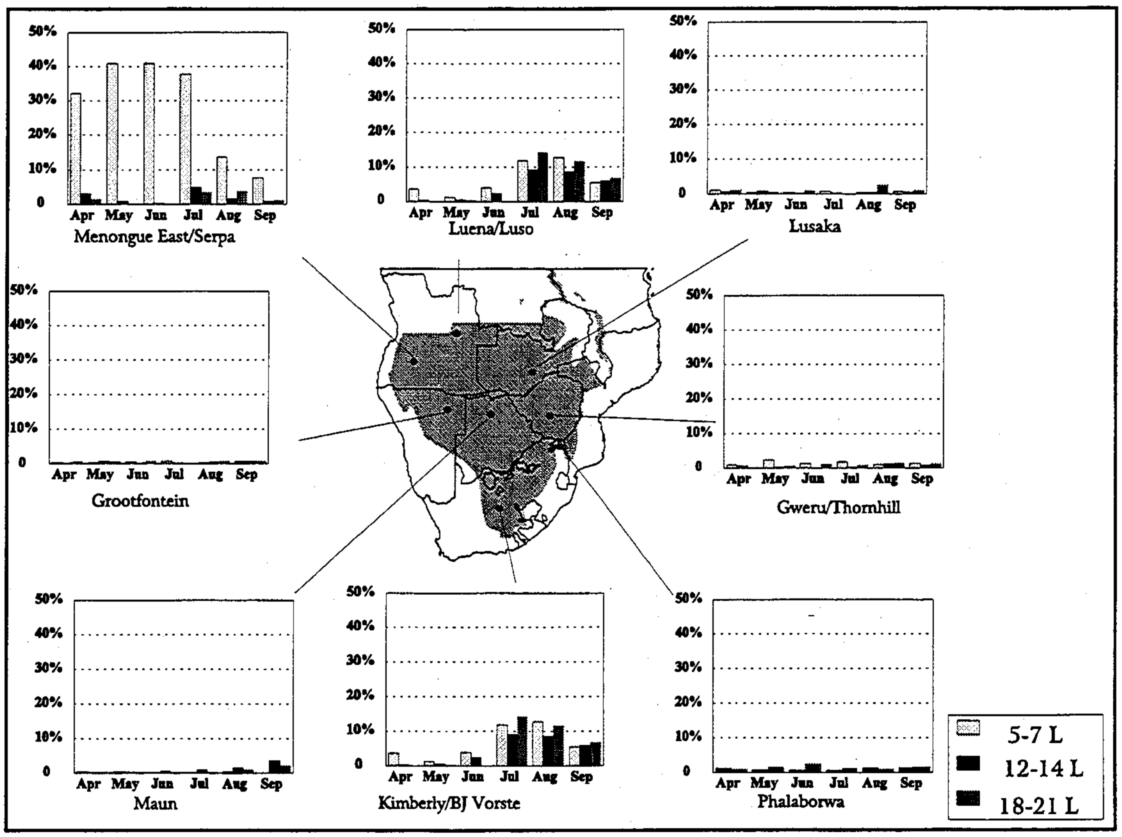



**Figure 5-12. Dry-Season Percent Frequencies of Visibilities Below 4,800 Meters.**

**Winds.** Surface winds are mainly easterly through southerly. The trades are not very pronounced due to the modifying effects of local topography. Wind directions are variable in early morning, but more defined during the afternoon. Mean speeds are between 3 and 13 knots. Winds greater than 27 knots are rare.

During the southern hemisphere winter, winds are also occasionally affected by the intrusion of cyclonic influence from South Atlantic depressions (mainly in southern Zimbabwe), which move on a northerly track across South Africa.

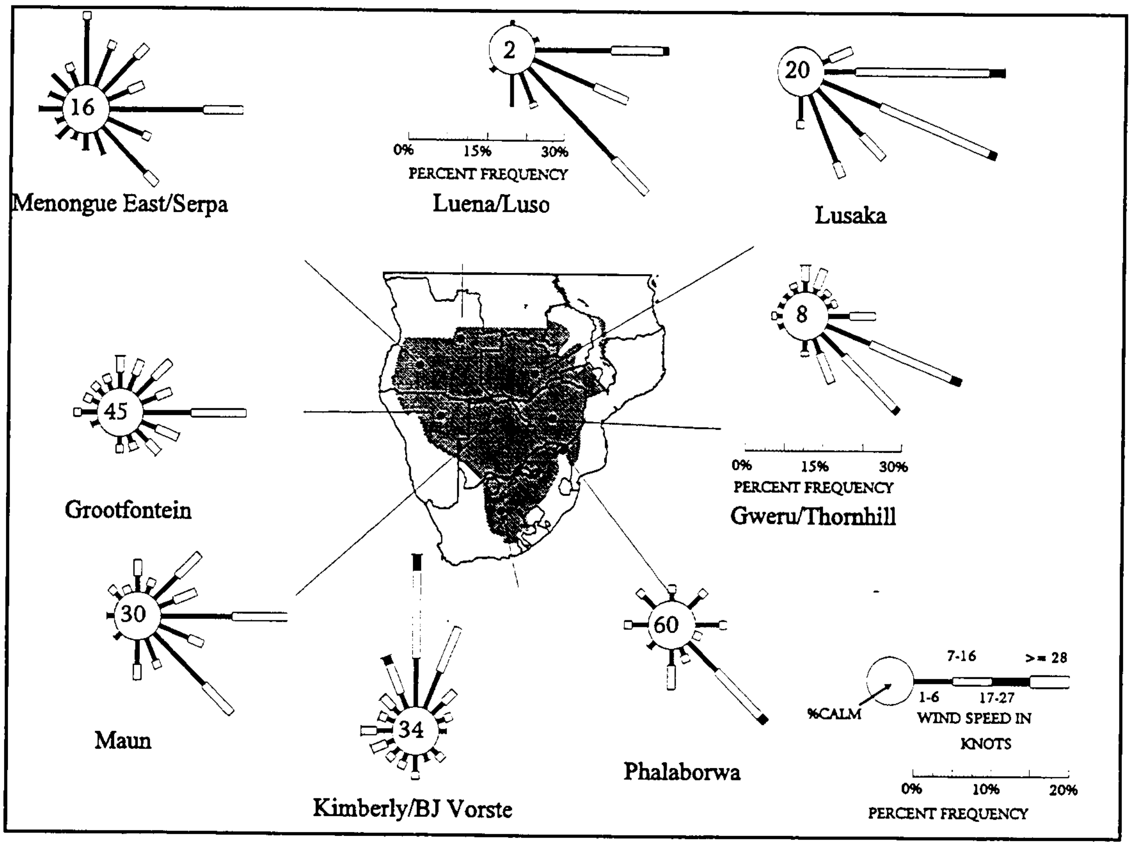



**Figure 5-13. July Surface Wind Roses.**

**Precipitation.** Rainfall is mostly confined to the wet season; only 5% of the annual rainfall occurs in the dry season. As seen in Figure 5-14, nearly the entire region receives less than 10 mm of rainfall. The only exceptions to the predominantly dry conditions are found in the mountain highlands of Zimbabwe, which can receive orographic rain at any time of the year. As mentioned previously, "Guti" conditions can develop during either season.

**Thunderstorms.** Although thunderstorms are infrequent during the dry season, they do occur, especially early in the season. Dry-season thunderstorms are often not accompanied by precipitation reaching the ground, but downbursts and turbulence can be expected. Hail is occasionally observed, but tornadoes are extremely rare.

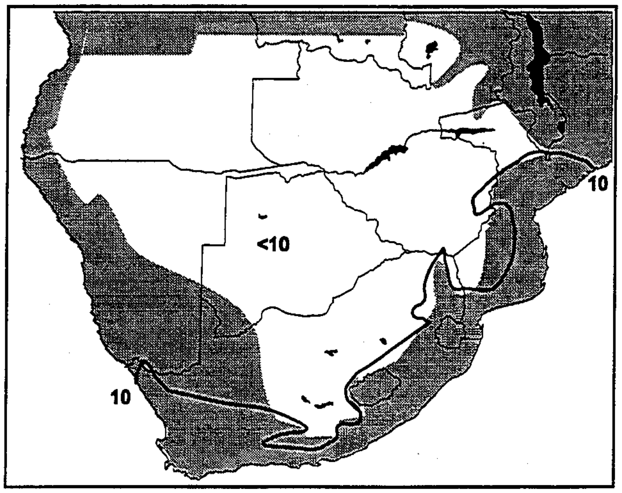


**Figure 5-14. July Mean Precipitation (mm).**

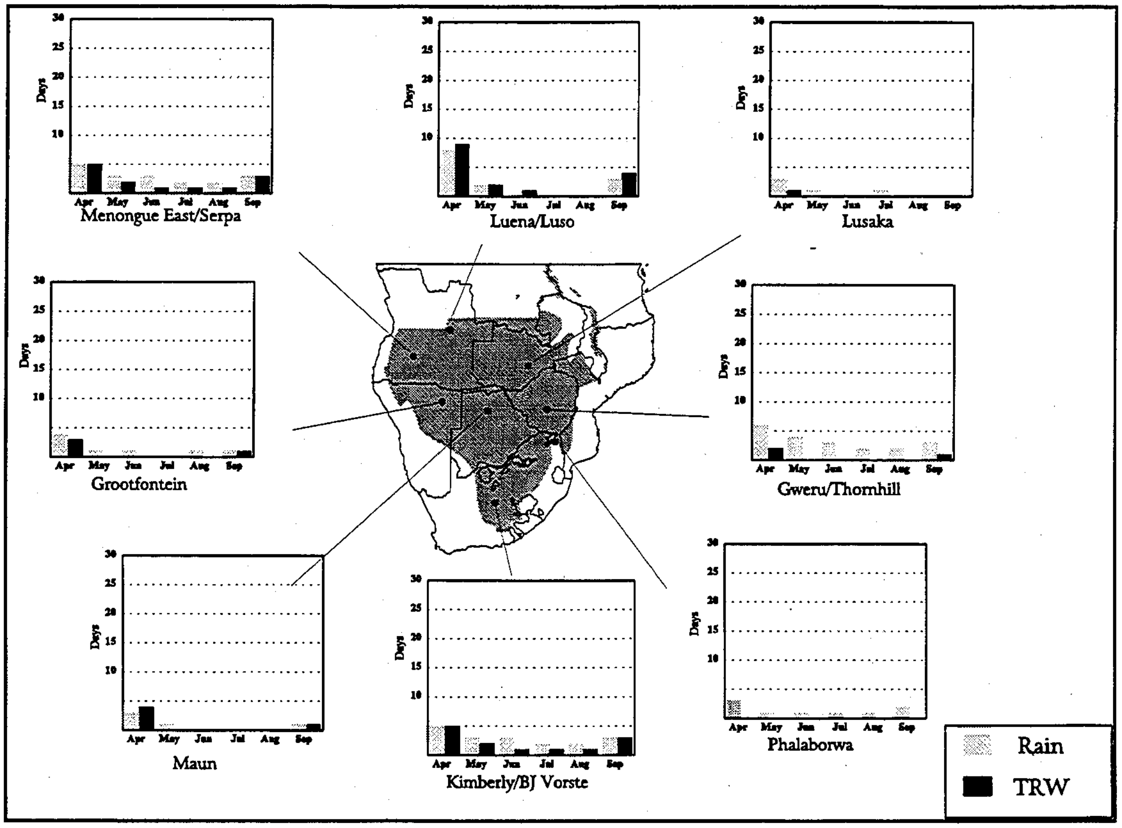


**Figure 5-15. Dry-Season Mean Monthly Rain And Thunderstorm Days**

**Temperatures** are modified by the high elevations on the Plateau; the result is cooler conditions than might be expected at these latitudes. Mean temperatures in all areas are generally lower in the dry season than in the wet season, but there are no sharply defined thermal seasons as found in more temperate latitudes. The lowest temperatures are recorded in July (see Figures 5-16 and 5-17).

Mean monthly temperatures range from 13° C in July on the high veldt to 30° C in the low-lying river valleys (especially along the Zambezi). The dry winter months are noted for wide diurnal ranges. Overnight frosts are common on the high Plateau; they can be very destructive. In low-lying areas such as river valleys (mainly below 900 meters), temperatures are consistently high all year.

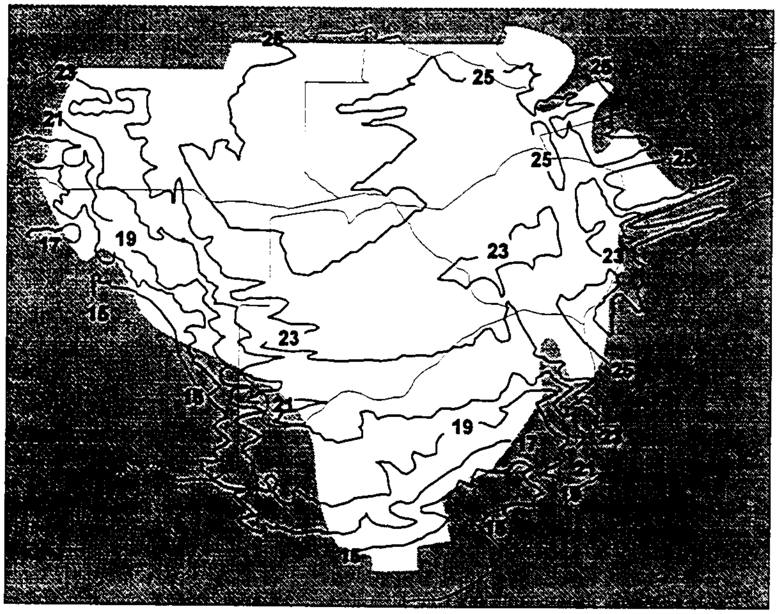



**Figure 5-16. July Mean Maximum Temperatures.**

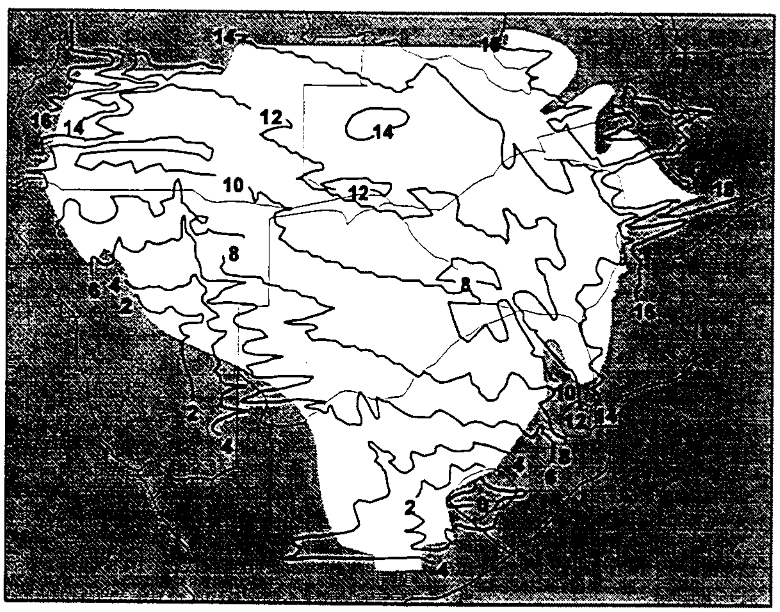
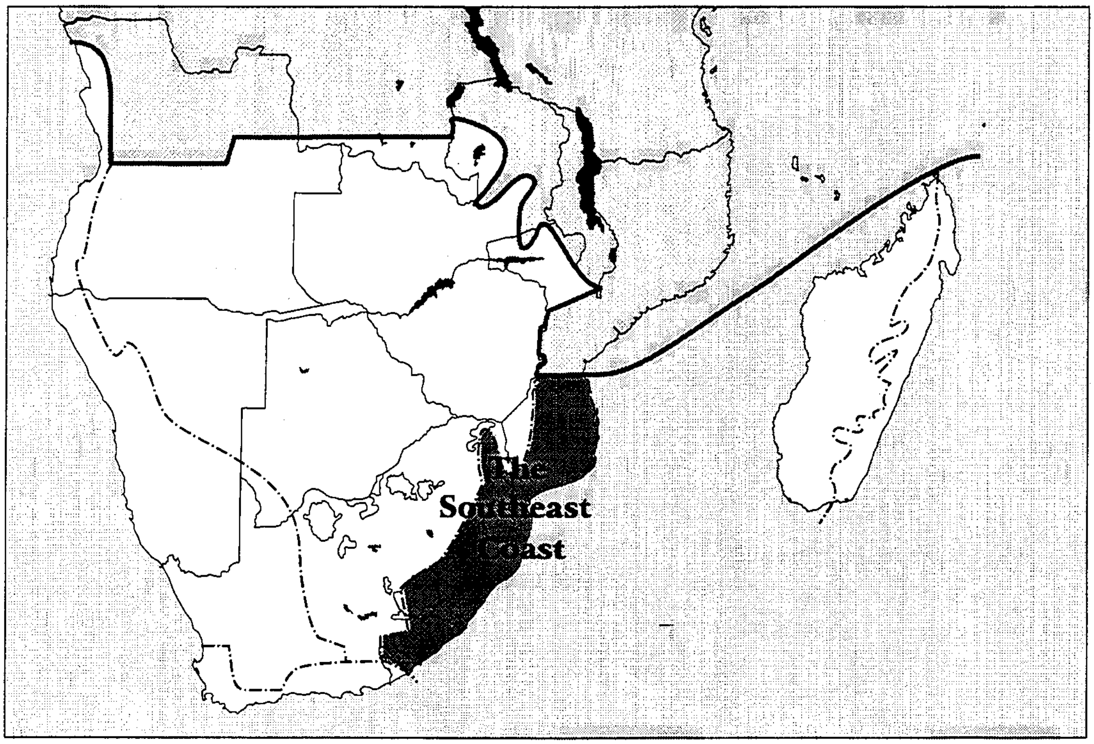



**Figure 5-17. July Mean Minimum Temperatures.**

# Chapter 6

## THE SOUTHEAST COAST

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for the southeastern coastal portion of the Republic of South Africa, along with Lesotho, Swaziland, and the southern half of Mozambique.



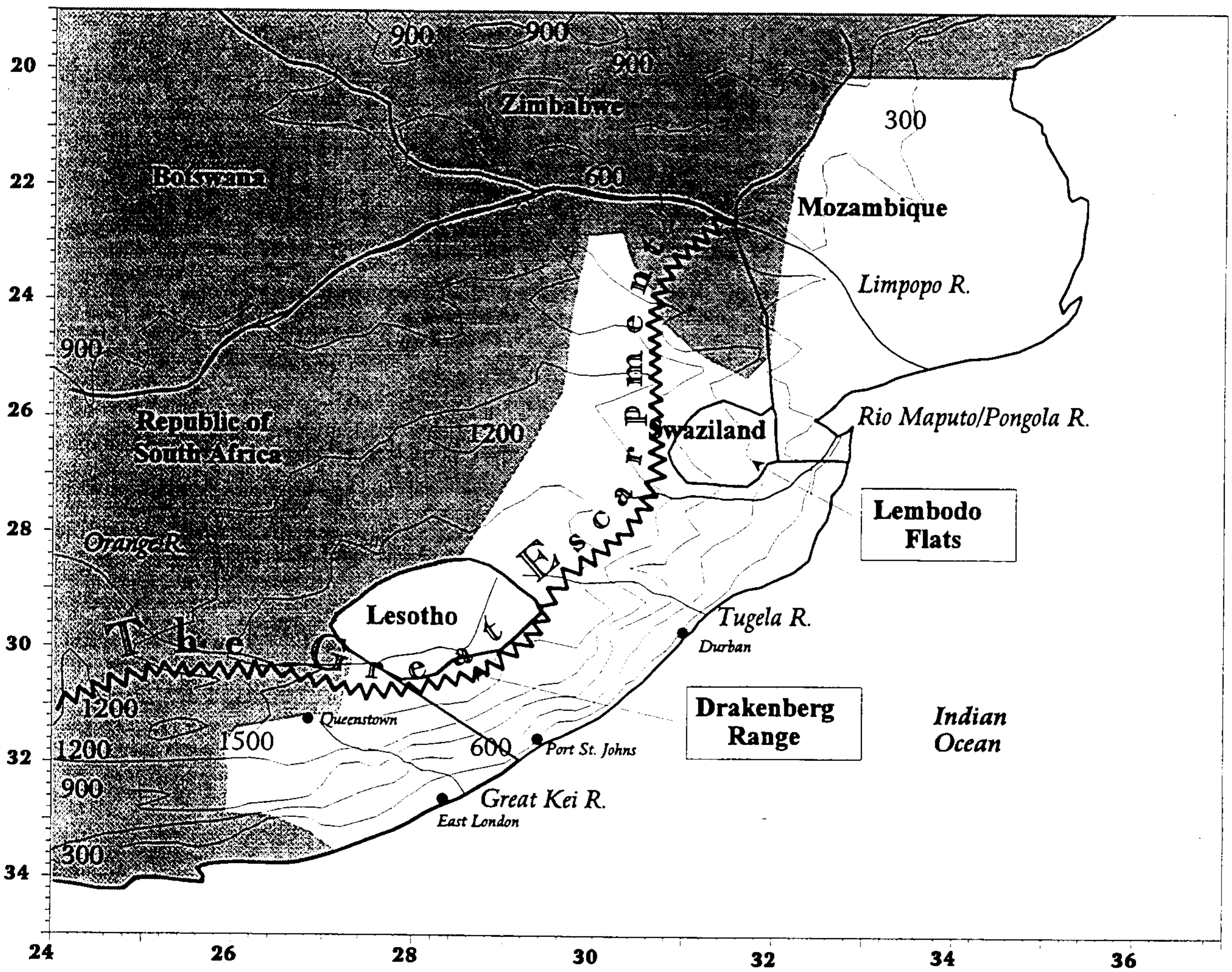



Figure 6-1. The Southeast Coast of Southern Africa.

**Boundaries.** The western boundary of the Southeast Coast is the ridgeline of the mountain range that rims the Plateau region. The northern boundary is the northern limit of the trades, while the southern boundary is determined by the limits of the wet and dry seasons. Specifically, the boundary is drawn from a point on the northeast coast westward to the Zimbabwe/Mozambique border, then southward to 25° S, 32° E (near the South African/ Mozambique border). From there it goes northwest to 23° S, 30 ° E, then south to 25° S, 30° E. It then proceeds southwest to northern Lesotho, where it follows the country's western border. From Lesotho, the boundary goes to 32° S, 27° E, and then 100 km west and south to 33° E, 26° W, and finally east to the coast.

## SOUTHEAST COAST GEOGRAPHY

**Major Terrain Features.** Three major terrain features influence the weather and climate of the Southeast Coast:

***The Great Escarpment*** is the most continuous topographical feature in Southern Africa. This series of mountain chains and outward-facing escarpments separates the inland plateau from the coastal lowlands. The most prominent of these is the Drakensberg range, which runs parallel to the Indian Ocean coast. In the northern Drakensberg (west of Durban), elevations are up to 2,100 meters; in the southern Drakensberg (west of Port St Johns), elevations exceed 3,300 meters. The escarpment continues southward, turning eastward north of Queenstown. The area's highest peak, Thabana Ntlenyana (3,482 meters), is in the Drakensberg range.

***The Immediate Coastal Region*** varies in width from about 16 km in the south to more than 80 km in the north. South of Port St. Johns, where numerous short streams have worn the soft rock into a vast number of hills and valleys, the country is rough and difficult to traverse. North of Port St. Johns, the coast is formed of sandstone that rises in a series of steps to the midland plateau. In the northern coastal regions where the Pongolo Rio Maputo/Pongola river runs, it can be swampy during the wet season. The coast becomes more marshy northward into Mozambique, where it turns into a broad plain with an average height of less than 200 meters. In their middle and lower courses, rivers flow in broad, flat valleys that sometimes flood during the wet season.

***The Midlands*** lie between the immediate coastal region and the Great Escarpment. This broad zone of hills and valleys is made up of weather-eroded sandstone and granite. Rivers have formed narrow gorges, some more than 300 meters deep.

**Rivers And Drainage.** Many small rivers and streams wind through the valleys of the area. The major rivers are described here; most start in the mountains and flow east to the Indian Ocean, but the Orange River flows west and empties in the Atlantic.

***The Great Kei River*** (in the South) flows southeast from near the Drakensberg range for 225 km to the Indian Ocean.

***The Tugela*** is a rough river with a series of waterfalls. It starts in the Drakensberg, runs 502 km, and drains more than 28,000 square km.

***The Limpopo River,*** one of the region's longer rivers, starts in northern South Africa and follows a semicircular course (first northeast, then southeast) about 1,800 km to the Indian Ocean. The Limpopo's lower and middle courses reflect seasonal changes, drying to a series of pools in the winter months and reaching flood proportions in the summer.

***The Pongola River*** (renamed Rio Maputo in Mozambique) has its origins in the northern interior. It flows west and northeast for about 250 km before emptying into the Indian Ocean.

***The Orange River,*** the longest river in southern Africa, originates in Lesotho's Drakensberg Range; this part of the river is steep and marked by numerous rapids.

**Vegetation** in the south is mostly parklike grassland. Trees and shrubs only grow in remote, sheltered valleys. Vegetation becomes more varied farther north; more than 2,600 species of ferns and flowering plants flourish throughout Swaziland. Mozambique's vegetation is mostly tropical and savanna. Along the coast, the coconut palm and mangrove are common. Bamboo and spear grass prevail in marshy areas.

## MAJOR CLIMATIC CONTROLS OF THE SOUTHEAST COAST

**Wet-Season Controls.** During the wet season, a thermal low is centered over the northern border of the Republic of South Africa (hereafter referred to as "South Africa") with a trough extending to the southern coast. The Indian Ocean and the South Atlantic Highs are at their weakest (and farthest south) with a weak ridge of high pressure extending between them along the southern coast. Flow from the relatively warm Indian Ocean has a long overwater trajectory around the high's northern periphery; it reaches South Africa as moist, unstable air. This airflow produces cloudiness and rain over much of the region.

**Dry-Season Controls.** As the dry season begins, the thermal low is replaced across South Africa by a ridge of high pressure that extends between the South Atlantic and Indian Ocean highs. The two high-pressure cells are at their maximum intensity; they are both displaced slightly northward of their summer positions. The Indian Ocean High is centered much closer to South Africa. The steep pressure gradient that had remained south of the continent in the wet season is displaced northward in harmony with the northward movement of the two oceanic highs. As a consequence, dry-season circulations are predominantly anticyclonic; cloud and precipitation amounts reach a minimum in most areas. The circulation from the Indian Ocean is more stable than during the wet season, but is still causes appreciable precipitation in some coastal areas.

**Polar air masses** move into South Africa regularly during the southern hemisphere winter. They often move from west to east, losing much of their energy by the time they reach the area. When the polar air is cold enough, snow may fall at higher elevations.

## SPECIAL CLIMATIC FEATURES OF THE SOUTHEAST COAST

**Local Winds.** Topography, differential heating, and proximity to the coast are three conditions that affect winds in this region. Land/sea breezes, mountain/valley winds, and slope winds occur, but within a relatively small area.

Sea breezes usually start 3 or 4 hours after sunrise and last throughout the day. As a rule, the wind veers from the northwest, the usual direction of the land breeze, to east or northeast, then backs gradually until it runs at shallow angles to the coastline. The tops of the sea breeze generally extend to between 500 and 1,000 meters AGL. The strong southwesterly winds that follow the passage of depressions are strong enough to overcome the sea breeze.

Combinations of land/sea breezes and other topographical winds produce complicated flow patterns. Winds between the escarpment and the southeast coast are classic examples of many different flows over the same location at the same time. During maximum heating and cooling,winds are flowing either up or down the escarpment. During transition periods, there may be as many as three different wind patterns from the surface to 1,000 meters. Slope and mountain-valley winds also make for many different wind patterns in the same location. Forecasters must rely on basic meteorology along with detailed terrain maps to make accurate wind forecasts in these areas.

**The Agulhas Current.** This is a warm current that flows south through the Mozambique Channel. Lines of cumulus and cumulonimbus often form over this current, which is discussed in detail later in this chapter.

**Berg Winds.** These are warm winds that originate in the interior and blow to the coast. They are responsible for remarkable rises in temperature along coastal areas. They occur mainly late in the dry season and early in the wet season—Chapter 2 provides a detailed discussion of berg winds.

**General Weather.** Even though this is the season of maximum cloudiness and precipitation, flying conditions over the area are considered good. Low clouds on the escarpment and in the uplands, however, can make flying hazardous. Tropical maritime air masses from the Indian Ocean provide most of the moisture and instability to produce rains. Cloud and precipitation amounts are substantial. Thunderstorms and rainshowers form from orographic lifting over the eastern highlands and from surface heating. The typical synoptic pattern has a trough extending southward from the Zaire/Zambian Low over the continent. Upper-level waves and frontal systems that bring clouds and precipitation occur regularly during the wet season. Occurrences of high-pressure cells reach a minimum in December.

Many different types of weather patterns bring clouds and precipitation. Easterly waves and lows reach their maximum during February. For easterly waves, low-level convergence occurs to the east of the surface trough where, at 500 mb or above, the flow is divergent. The result is strong uplift that can sustain rainfall without pronounced instability. Behind the wave, rain falls for a couple of days. With an easterly low, surface convergence occurs to the east, resulting in low clouds and rain.

Westerly waves, in combination with ridging at 500 mb, often produce widespread rainfall as surface flow brings in moist, unstable air from the Indian Ocean. This pattern occurs most often in October and February. The flow may combine with orographic lifting to produce rain or thunderstorms.

Cut-off lows start as troughs in the upper westerlies and deepen into closed circulations. These lows, which account for many of the flood-producing rains, are most common early in the wet season. Rainfall tends to be confined to coastal regions.

Tropical cyclones are most common in the wet season, especially during January and February. Tropical cyclones that affect this region originate in the Indian Ocean northeast and east of Madagascar, then move south through the Mozambique channel. Usually one to five of these pass along this route every year, but they seldom penetrate to 30° S. The storms occasionally cross the coast, but they seldom move inland of the escarpment. Those that do move inland decay rapidly. Even so, these storms are capable of producing heavy, flood-causing rains over several days.

**Sky Cover.** The wet season is the season of maximum cloudiness. Afternoons are generally cloudier than mornings. The most common types of low clouds are cumulus and fractocumulus, accounting for about 60% of the low cloud observed. The average height over the coast at Durban is about 3,000 feet, but over the hills that rise steeply from the coast, bases are often less than 2,000 feet. On an average day in January at Maputo, more than half the cloud in the morning is cumulus or towering cumulus that forms due to daytime heating. These clouds often clear after sunset. Bases vary between 1,000 and 3,000 feet ; tops can rise to 25,000 feet.

Cumulus and cumulonimbus form over the warm Agulhas Current at night, and appear in the morning as low banks about 25 or 30 km from the coast. These often disperse about an hour or two before noon. Bases are usually between 1,200 and 1,500 feet, but may occasionally be only a few hundred feet.

Figure 6-2 shows percent frequencies of ceilings during January. Most ceilings are caused by thunderstorms. Frequencies increase to the north, where the NET enhances thunderstorm development.

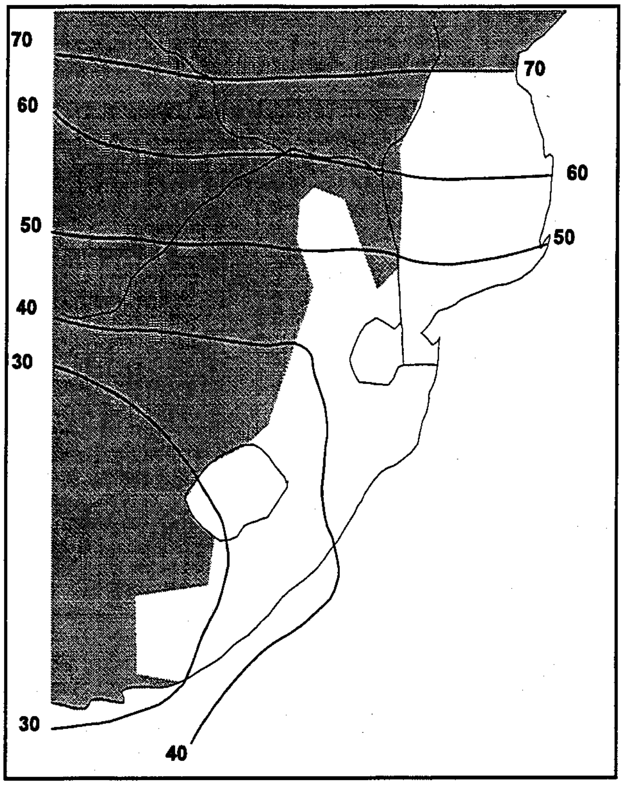


**Figure 6-2. January Percent Frequencies of Ceilings.**

Low ceilings (Figure 6-3, next page) are most frequent along coastal sections and inland to the top of the Drakensberg range. Ceilings are below 3,000 feet as much as 30 to 55% of the time in these areas; the tops of the Drakensberg may be shrouded in clouds. Clouds from fronts, waves, and troughs are also mainly cumulus and cumulonimbus. Average ceiling heights are 1,000 to 2,000 feet , but they may go as low as 500 feet in precipitation. Tops can extend to over 40,000 feet. Ridging often produces extensive but shallow stratocumulus cloud cover along coastal and adjacent inland areas, with bases around 2,000 feet and tops around 4,000 feet.

**Sky Cover, Continued.** Figure 6-3 shows that low ceilings are most common in the morning and evening. Clouds that form at night over the Agulhas Current move inland with the sea breeze, causing short-lived ceilings with bases at 1,000-2,000 feet in the morning. Xai Xai and Inhambane have higher frequencies at midday, probably because the southerly flow during the night and morning provides added moisture for midday cloud development. During the afternoon, clouds develop along the mountains to the west of the southern coastal stations; these clouds build back over those stations, increasing the chances for low ceilings in the evening.

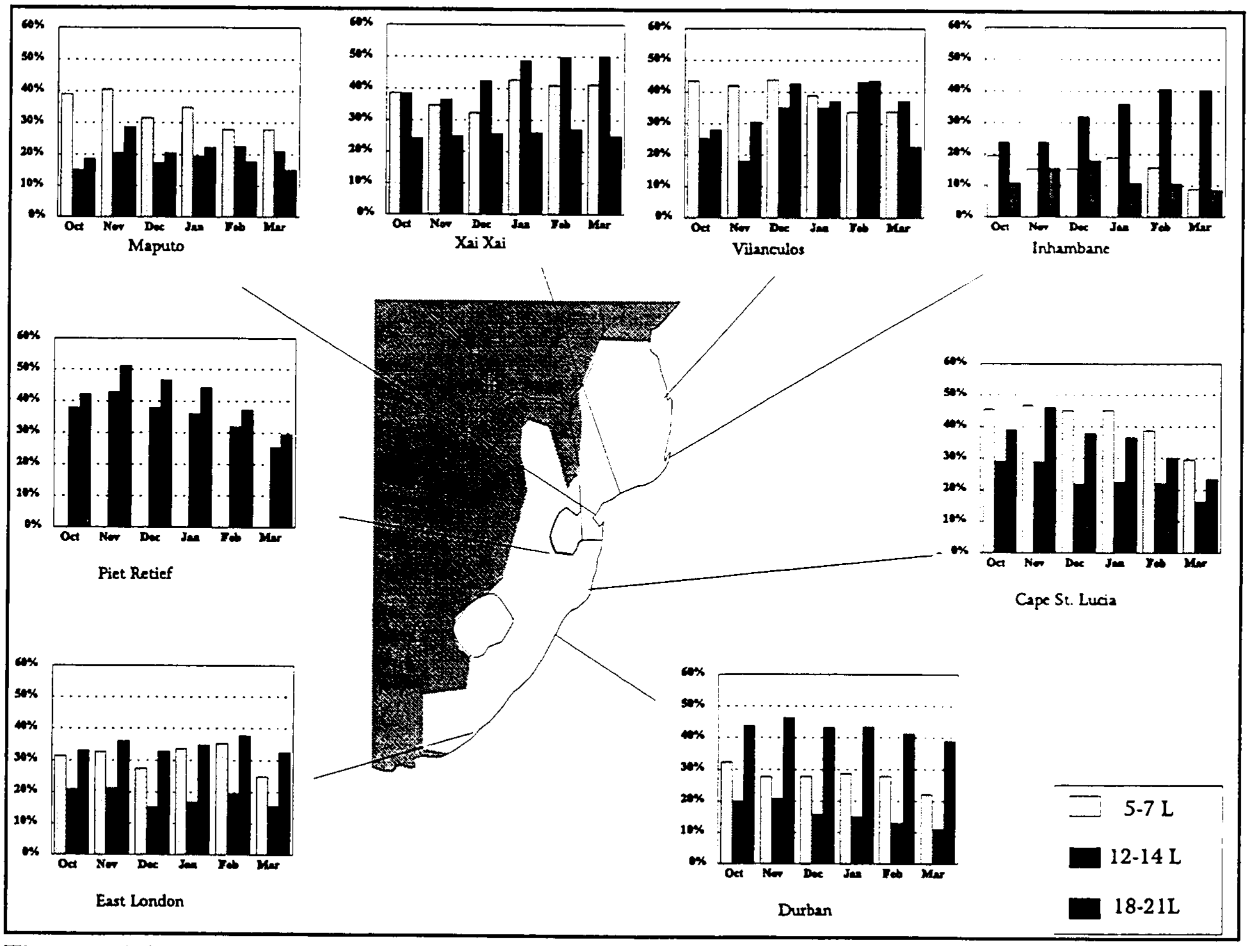



**Figure 6-3. Wet-Season Percent Frequencies of Ceilings Below 3,000 Feet**. The 0500-0700L data for Piet Retief was not available.

**Visibility** over the whole area is generally good, but low clouds sometimes obstruct visibilities on mountain slopes. The main cause of poor visibility on the coast is rain. Visibilities can go below 1,600 meters for short periods during brief but intense thunderstorms. Dust from berg winds sometimes reduces visibilities, but generally not below 8 km. Haze is also observed, but it rarely causes significant reductions.

Fog only occurs as a rare, local phenomenon; the lowest visibilities are mostly confined to the morning. Flow from the highs located to the east and southeast occasionally causes coastal fog and stratus. Coastal fog also sometimes develops following the passage of low centers. Fog is most common at Durban, where it lowers visibilities to below 1,000 meters on 4-7 days a month. Radiation fog may form in the valleys of the highlands; it reaches its greatest density during the morning, and usually dissipates by noon. The mean number of days a month with visibilities less than 1,000 meters due to fog is about 2 for all locations except Durban.

As shown in Figure 6-4, most stations see low visibilities less than 5% of the time. Piet Retief has higher values, possibly because its location with respect to topography enhances fog development.

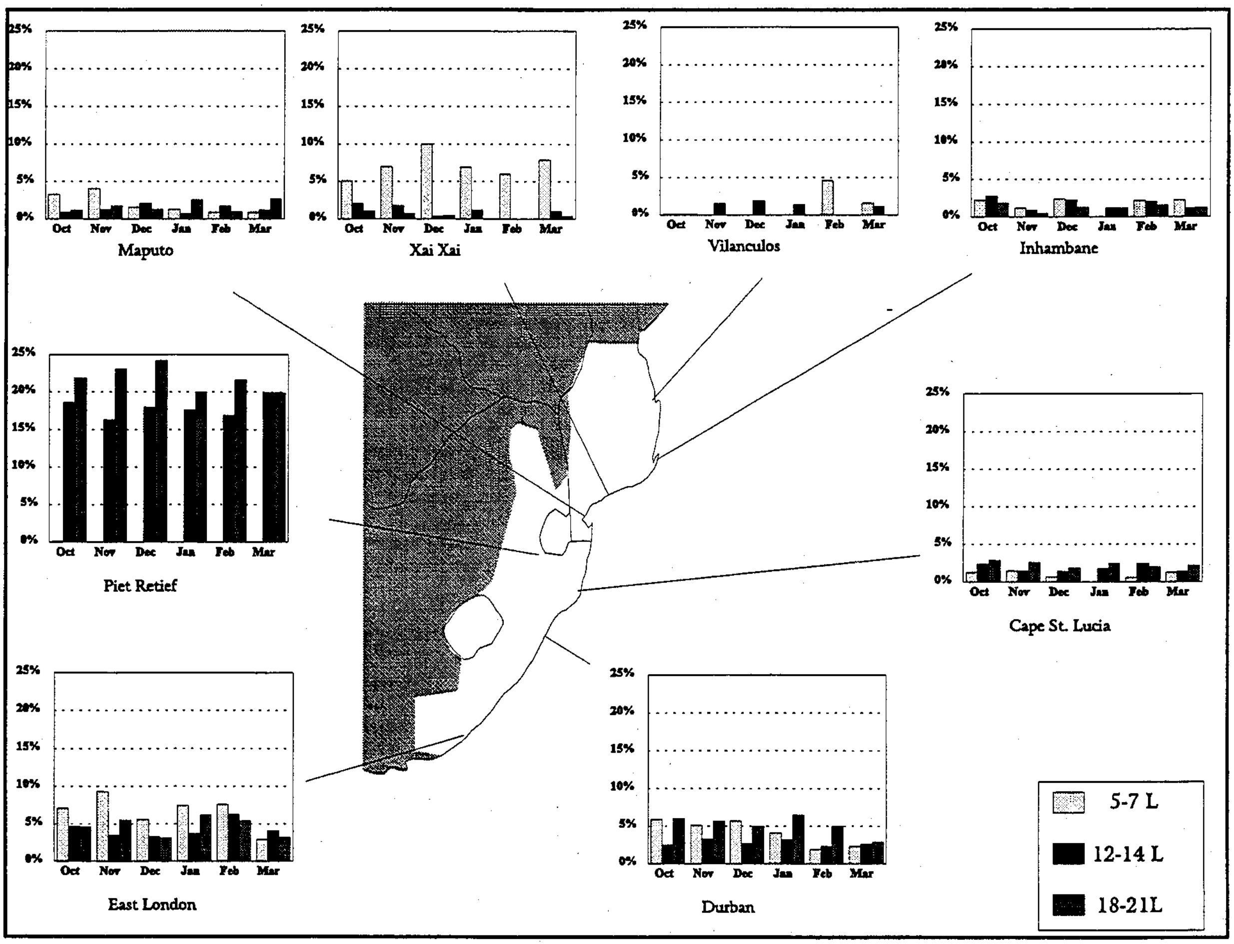



**Figure 6-4. Wet-Season Percent Frequencies of Visibilities Below 4,800 Meters.** The 0500-0700L data for Piet Retief was not available.

**Winds.** The prevailing surface winds in the southern half of the southeast coast are from the northeast and southwest, roughly parallel to the coastline (Figure 6-5). Along the northern half, the trades produce winds from the east and southeast. Over the southern part of the interior, the prevailing wet-season direction is southeast. The land/sea-breeze cycle is present throughout coastal areas. September and October are the windiest months; March and April are the calmest, except in the south-central coastal region, where July is calmest. On the coasts, winds are subject to regular variation because of the land and sea breezes.

The sea breeze begins 3 or 4 hours after sunrise and lasts throughout the day. The land breeze, which generally begins shortly before midnight, seldom exceeds 5 knots.

Southerly winds have only small diurnal variation in both speed and direction. Southwesterly winds, which are almost nearly always associated with steep pressure gradients, are strong enough to overcome the sea-to-land component during the day. Moreover, they are usually associated with cloudy weather that suppresses the differential heating between the land and sea.

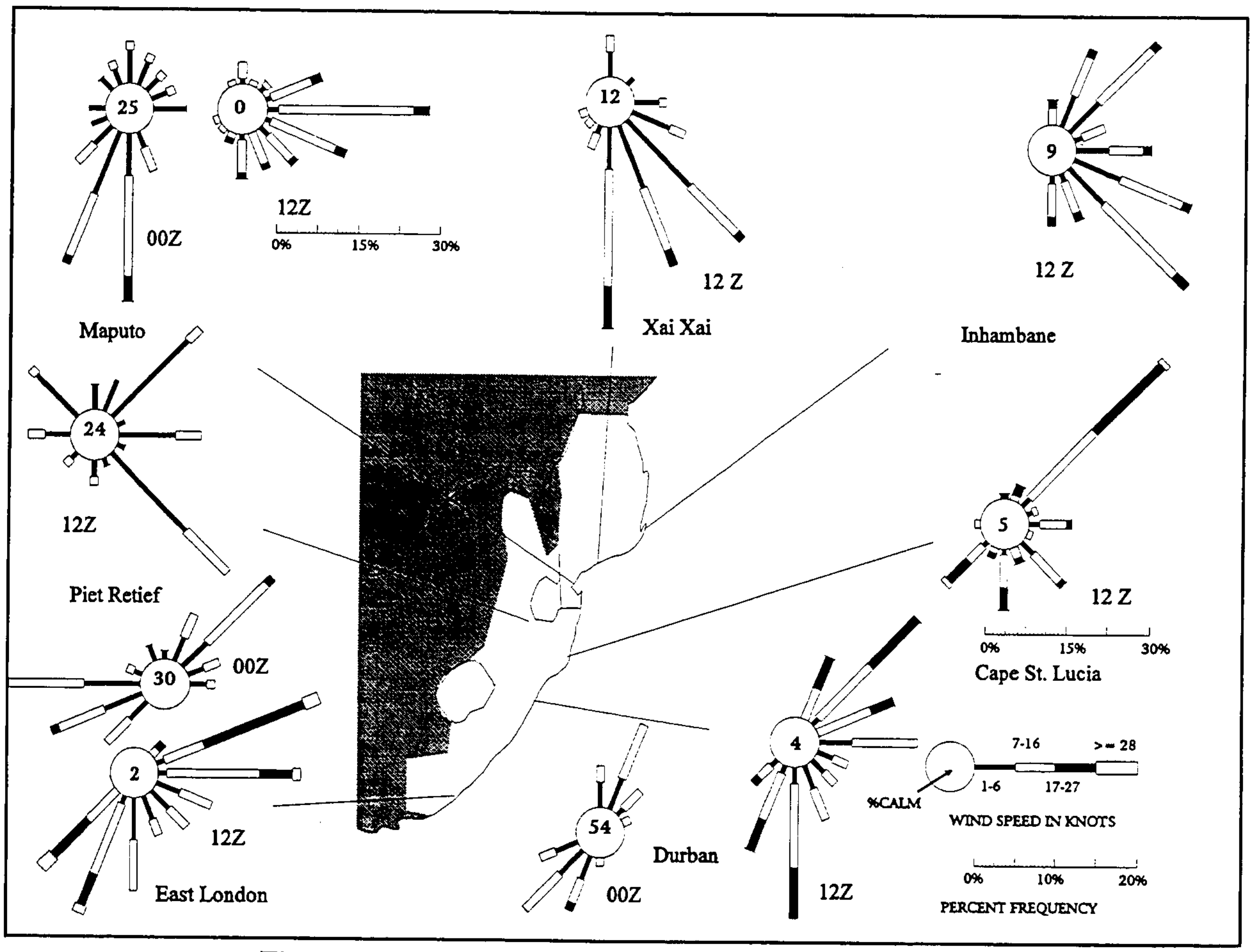



**Figure 6-5. 00Z and 12Z Surface Wind Roses for January.**

Interior winds are more strongly influenced by topography and thermal gradients than by synoptic features. Large-scale downslope flow develops at night between the cool mountains and the warmer plains. Upslope winds develop between the cooler plains and warmer mountains by day. These are particularly well developed seaward of the escarpment.

Figure 6-5 showed winds at 00Z and 12Z; some stations were omitted because they had a poor observation count at 00Z. Note the relatively high speeds during the afternoon. The differences between the three northern coastal stations and the three southern coastal stations are due to the fact that the northern stations are exposed to the trade winds, while the southern stations are south of the trades. Consequently, the sea-breezes are easterly to southeasterly at northern coastal stations, and easterly to northeasterly at southern coastal stations winds. Warm, northwesterly Berg winds affect coastal areas, mainly in the early part of the season (see Chapter 2).

**Winds Aloft.** Figure 6-6 shows the upper-air wind roses for the region. The Subtropical Jet doesn't affect the area during the wet season as it does during the dry season. Since the boundary between easterlies and westerlies is nearby, winds at Maputo are variable between 850 mb and 500 mb. Durban shows less variability in the lower layers because it is farther south.

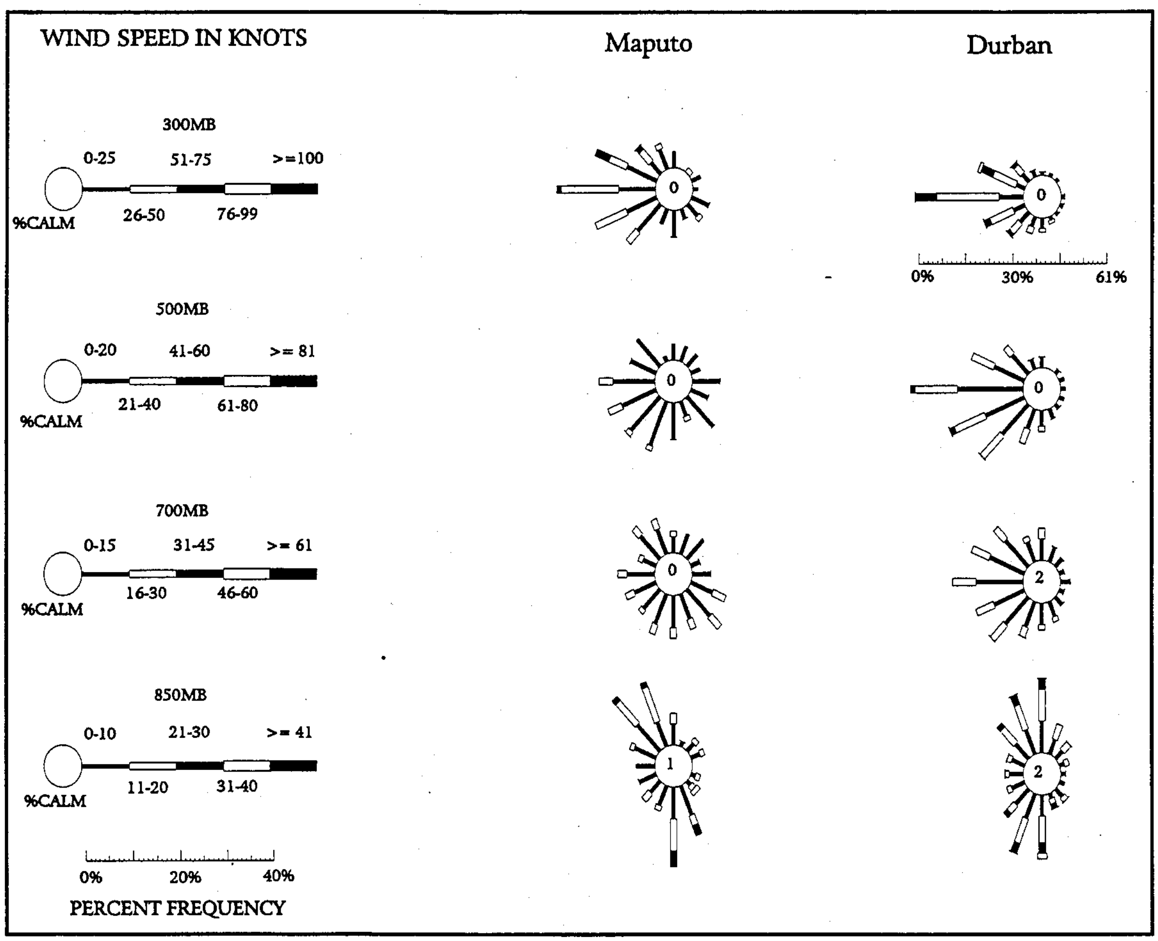



**Figure 6-6. January Upper-Air Wind Roses.**

**Precipitation.** About 80% of the region's annual rainfall occurs during the wet season, much of it from showers and thunderstorms. In the coastal areas, rainfall is distributed fairly evenly throughout the season, but there is a tendency for a maximum to occur in March. This is especially noticeable at Cape St. Lucia, where the average for that month is about 215 mm, compared with 140 mm in February. Even on the coast, where there is a fair amount of rainfall in the winter months, the rains seem to decrease abruptly at the end of March. At Cape St. Lucia, there is less than half as much rain in April as in March. The decline is even more noticeable inland.

Most of the rainfall on the coast is associated with passing depressions. Many appear first in the region of the southwest Cape and travel eastward, bringing rain to the whole of the south and southeast coast. The cool air in the rear of these depressions brings heavy rain to the hills of the interior, and showers over the warm sea. The latter are especially noticeable in the early morning. Around the escarpment, orographic rain and drizzle is a common feature whenever an anticyclone skirts the coast, forcing moist maritime air against the mountain ranges.

Most of the eastern highlands and all of the coast receive about 760 mm or more of rainfall a year. Point amounts vary greatly according to exposure. The greatest amounts fall along the upper slopes of the Drakensberg, with over 1,800 mm a year at some isolated locations. As shown in Figure 6-7, mean precipitation amounts for January are greatest in northwest Swaziland and northwestward along the escarpment. Northern coastal areas have relatively high amounts due to the proximity of the NET and the tropical depressions that skirt the area.

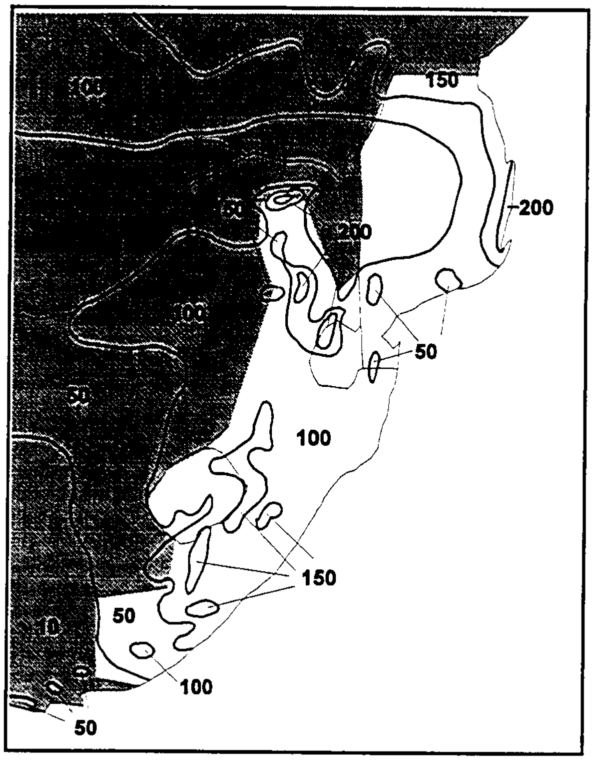


Figure 6-7. January Mean Precipitation.

Marsh and swamp areas along the northeast coast near the Rio Maputo and Pongola Rivers normally see extensive flooding during abnormally wet years. The driest parts of the area are the Lebombo flats and the upper and middle sections of the Great Kei River below Queenstown. These areas have no orographic influences to enhance precipitation.

On average, precipitation falls on more than 100 days a year along much of the coast. Southern coastal stations have 10-20 rain days a month; stations farther north have only around 5 days a month (see Figure 6-8).

**Thunderstorms.** Much of the region's rainfall comes from thunderstorms, which have a clear diurnal variability. Thunderstorms occur on about 5 days a month at all stations, with slightly higher occurrences inland (see Figure 6-8). In the central coastal regions, downslope winds from the Drakensberg Range blowing offshore may produce late-evening rainfall peaks. A trough in the tropical easterlies commonly promotes storm formation. Frontal passages also frequently trigger storms.

Thunderstorms at sea generally occur in the rear of depressions or in the clearing stage after the passage of a front, when cold air from the south and southeast becomes unstable as it passes over the Agulhas Current. Thunderstorms over the sea are most common at night.

Hailstorms occur most often from October to December; the highest frequency is in November. Some storms have caused considerable damage, killing small livestock and damaging buildings. About a third of the hailstorms reported were severe enough to damage buildings or crops. The diameter of hail is usually no larger than 1 cm, and hailstones larger than 3 cm are very rare. Destructive hailstorms are not confined to the wet season.

Very little information is available concerning the diurnal occurrence of hail; but over the eastern plateau, the indications are that hail falls mostly between the hours of 1200-2200L, with a maximum at 1700-1800L. Although rare, tornadoes have been known to accompany thunderstorms, especially in the highlands.

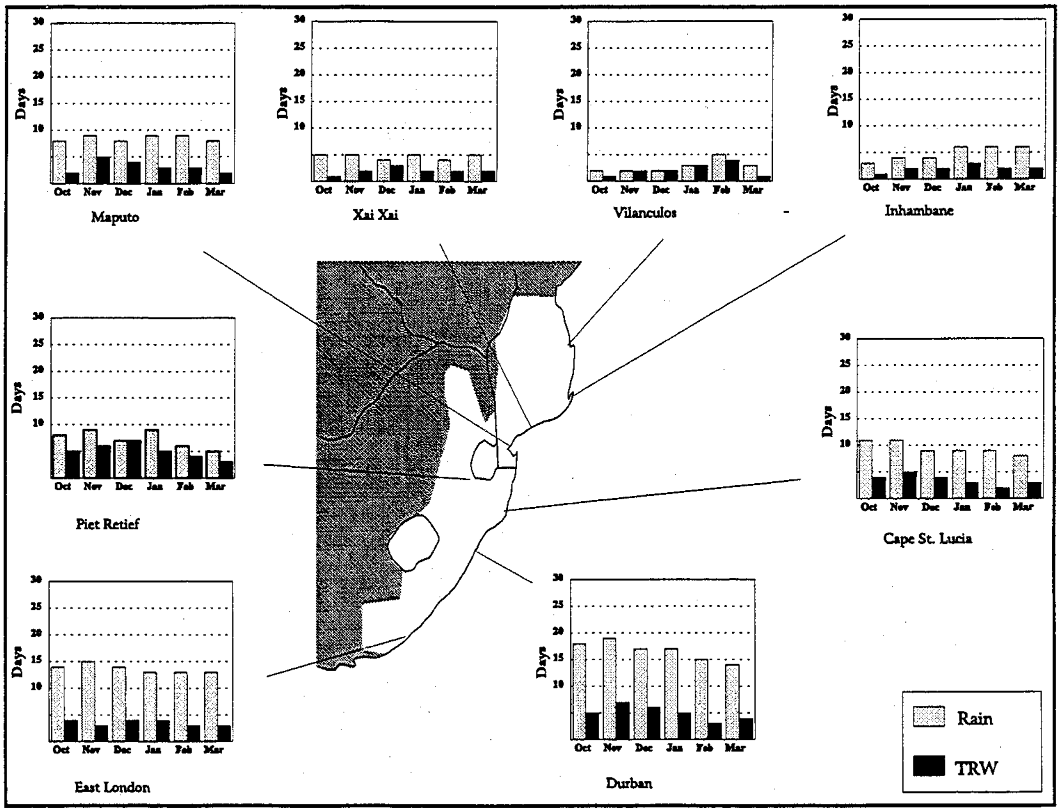



**Figure 6-8. Wet-Season Mean Monthly Rain and Thunderstorm Days.**

**Temperatures.** Mean highs and lows are shown in Figures 6-9 and 6-10. Temperatures vary little on the coast (about 5 degrees C). In the interior highland areas, temperatures are about 5 degrees cooler than the coast and diurnal variations can be as much as 10 degrees. Extreme highs are in the upper 30s to low 40s, Possibly caused by Berg winds. Extreme lows are usually in the lower teens, but some isolated mountainous areas may see extremes in the single digits.

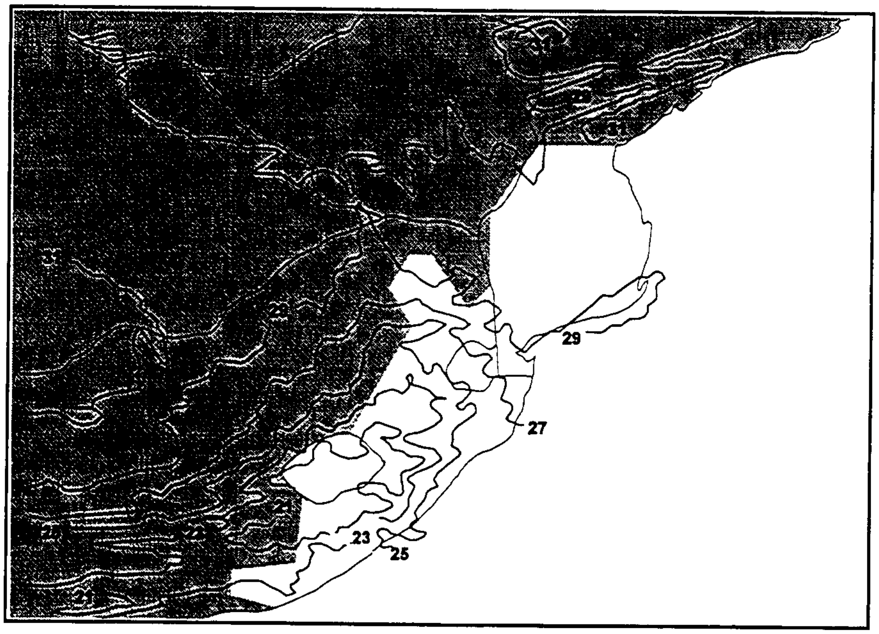



**Figure 6-9. January Mean Maximum Temperatures.**

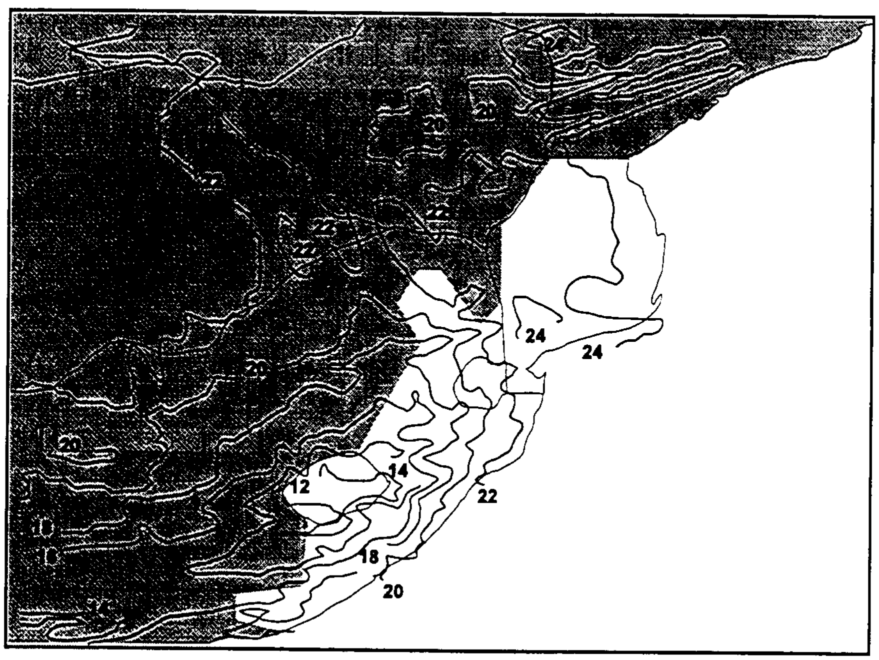



**Figure 6-10. January Mean Minimum Temperatures.**

**Other Hazards**. The main directions of the sea swell are easterly and southeasterly. There is fairly close agreement between the direction of the wind and the swell, except inshore. where northeasterly winds and rough seas may coincide with a southeasterly swell. This combination is responsible for the bad anchorage outside Durban harbor, and occasional difficulty in entering the harbor.

Rough seas, which occur about 20% of the time, generally accompany southwest winds which, blowing against the Agulhas current, raise a steep breaking sea that increases rapidly as the wind strengthens. The highest and most dangerous seas occur near the 100-fathom line. With northeast winds, the seas increase more gradually, usually becoming rough only during a strong gale.

**General Weather.** High pressure dominates the region, especially over the interior plateau during June and July. Subsidence causes warm and dry cloud-free weather that can persist for up to 2 weeks. During these periods, heat waves may occur; abrupt temperature increases from one day to the next often exceed 5 degrees C. Heat waves are associated with strong continental highs; they occur along the coast because of subsidence and warming associated with Berg winds.

Coastal lows are also common during this season. These lows are shallow (seldom deeper than 850 mb); they seldom produce precipitation in excess of mist or fine drizzle (see Chapter 2). Occasionally, a coastal low becomes coupled to a wave aloft and develops into a coastal depression that produces rain on a larger scale. Hot berg winds blowing at more or less right angles to the coast usually accompany these lows. The bergs (hot, foehn-like winds) are among the most unpleasant features of the coastal climate. Bergs may sometimes persist for days until the wind switches to the southwest, accompanied by a large drop in temperature. Coastal lows often tend to move seaward near or just north of Durban. After a fairly strong northeasterly wind, there is often a sudden switch to strong *southwesterly* winds as the low passes, giving rise to the locally named "buster" wind of the Durban area. Immediately following the onset of the southwester, large amounts of low clouds frequently move in from the sea and blanket the hills near the coast.

A large-scale cold-air influx called the "normal cold snap" is common late in the season. Pre-frontal rain falls when a cold front moves across the coast. Snow is likely on the high mountains.

**Sky Cover.** Skies are least cloudy during the dry season. Cumulus is the most common cloud, occurring both with frontal/wave activity and through diurnal heating. Bases are typically 2,000-4,000 feet; tops are 10,000-15,000 feet. Maximum development is in the afternoon, in association with maximum heating.

With the passage of a coastal low, stratiform clouds move along the coast and penetrate inland toward the escarpment; orographic clouds and fog cover the hills. Inland penetration of clouds depends on the depth of the moist layer. Upper-air soundings at Durban often show this depth to be between 7,000 and 9,000 feet. Bases can be as low as 1,000 feet along the coast; the higher hills and mountain tops along the escarpment are sometimes obscured. With invasions of cold air from the southwest, deep layers of nimbostratus and rain persist for prolonged periods without the characteristic clearing showers behind the front. Bases can be as low as 500 feet, with tops over 5,000 feet.

As shown in Figure 6-11, frequencies of ceilings increase to the south, the opposite of the wet-season trend. This apparent reversal occurs because southern areas are more likely to be affected by low-pressure systems.

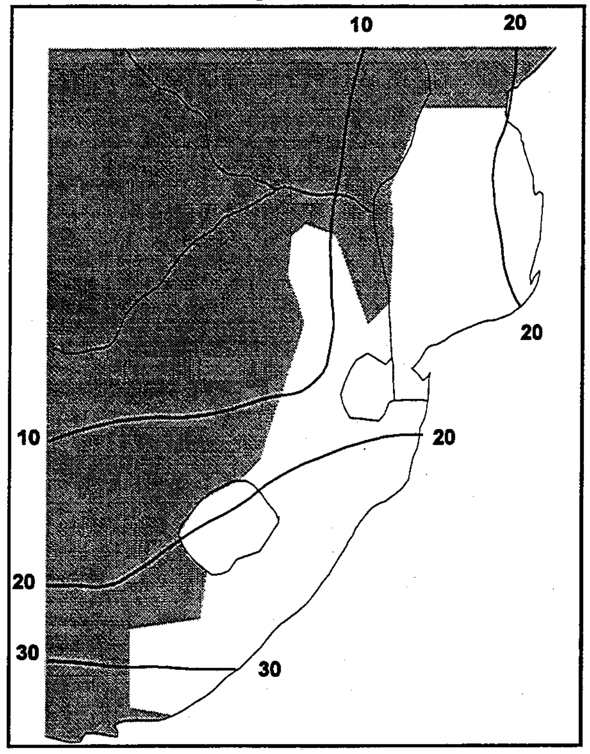



**Figure 6-11. July Percent Frequencies of Ceilings.**

**Sky Cover, Continued.** As Figure 6-12 shows, low ceilings occur most often in the afternoon and early evening. Banks of cumulus congestus and cumulonimbus occasionally form over the Agulhas Current. They are usually too far seaward to be significant, but when they sometimes move toward the coast, they cause heavy showers and thunderstorms. This is more likely in the south toward Port St. Johns and along the bulge of the coast towards Cape St. Lucia.

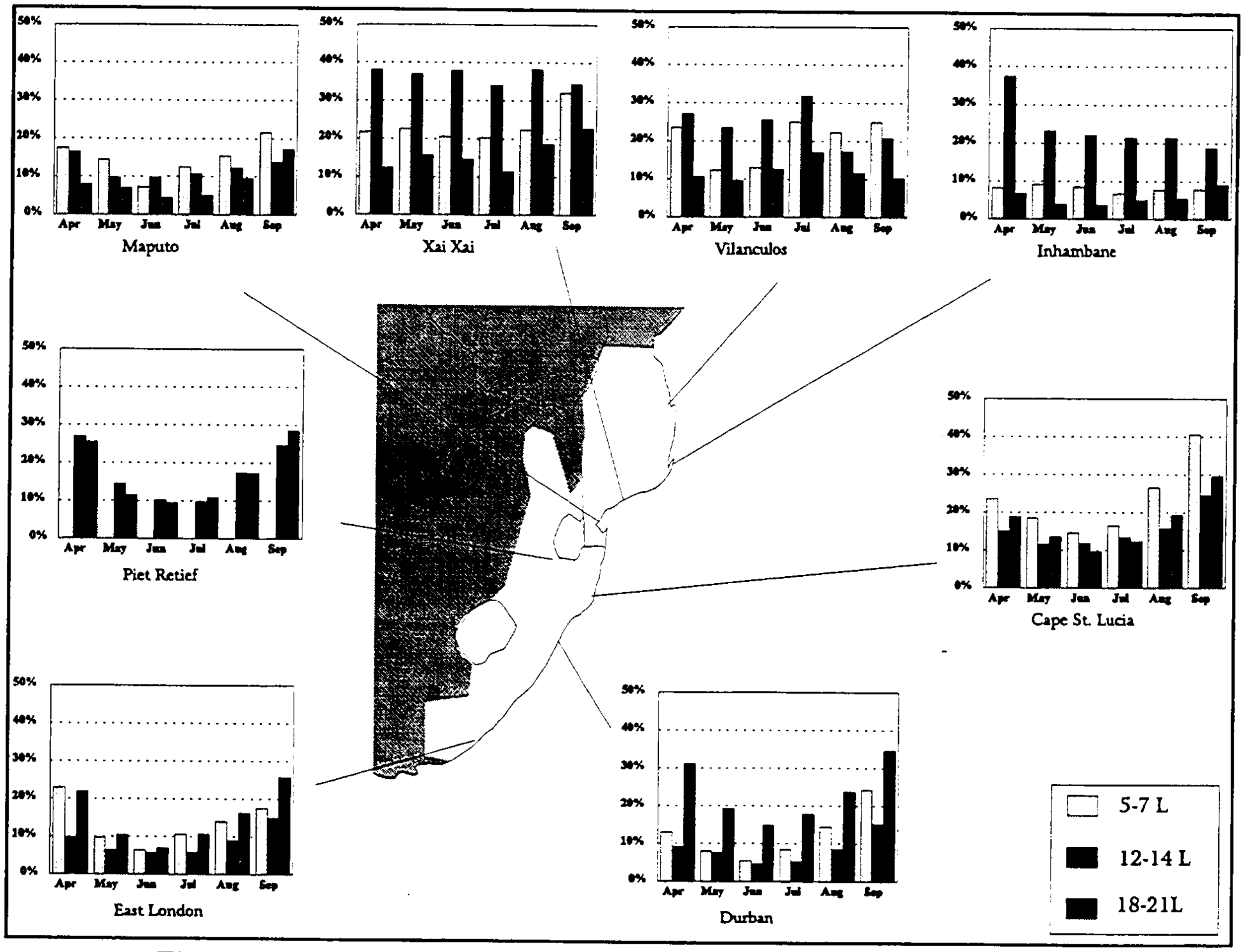



**Figure 6-12. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet.**

**Visibility** is generally good throughout the area. Occasional poor early morning visibility is due mainly to haze, which is thickest when there is a light land breeze after a day of northeasterly wind. On these occasions, there is generally a shallow inversion and very little surface turbulence; as a consequence, haze is slow in dispersing. Near Durban, haze is intensified by smoke spreading out below the haze top, reducing visibility near the shore to about 3 km.

Two other causes of poor visibility are spray from the surf and smoke from grass fires. With rough seas, a thick salt-haze appears along the coast, making it difficult to recognize landmarks from the sea. Grass fires, which occur chiefly during this season, have a similar effect; unless there is a strong wind to disperse the smoke, visibility can fall as low as 1,000 meters.

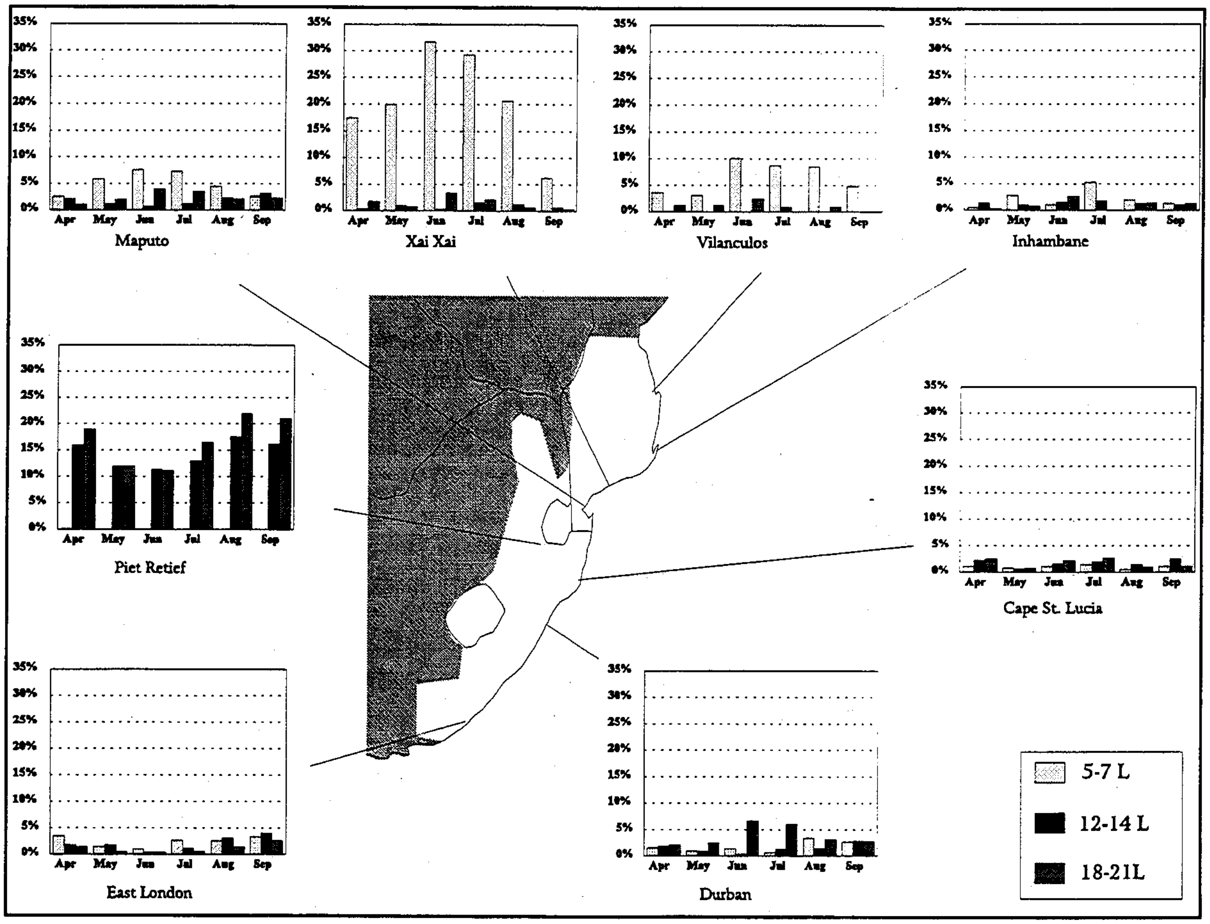



**Figure 6-13. Dry-Season Percent Frequencies of Visibilities Below 4,800 Meters.**

**Visibility, Continued.** On the central coasts, thick ground fog often forms after sunset, when the ground has cooled. This is fairly common; the fog is often thick enough to interfere with flying operations, but it doesn't affect shipping. Ground fog is evident in Figure 6-13, which shows Xai Xai with a relatively high frequency of poor visibility during morning hours. Fog is most common at the mouths of rivers.

In the interior, visibilities may occasionally be reduced by the formation of low clouds and fog on hillsides. This is especially noticeable northwest of Durban, where a narrow strip of land between 300 and 1,300 meters high is known locally as the "mist belt" because low cloud and fog frequently form there at night. The fog, which is usually associated with light winds from a southeasterly direction, forms soon after sunset and remains until an hour or two after sunrise. It seldom remains after 1000L. A similar form of fog occurs on the mountains west of East London, where it also forms in the evening and disperses after sunrise.

Dust storms occasionally reduce visibility to less than 6,000 meters in the interior. They are most common at the end of the dry season, when fine dust is sometimes carried to great heights, spreading out and obscuring the landscape like a thick cloud. Severe dust storms often occur before thunderstorms, but even the worst of them don't last long. They are usually followed by rain, after which the atmosphere becomes clear.

**Winds**. The overall wind pattern is determined mainly by topographical and diurnal influences. Trade winds are easterly along the northern half of the area. Berg winds are most common in the later part of the season (see Chapter 2).

The wind regime is best understood by comparing the all-hour wind roses (Figure 6-14) with the 00Z and 12Z wind roses in Figure 6-15, next page. Winds are strongest in the afternoon when the sea breeze is strongest. Durban has a high frequency of calm winds (as seen in Figure 6-14), but Figure 6-15 (next page) shows that there are strong afternoon winds from both the sea breeze and frontal/low pressure systems.

The diurnal variation of surface winds is very noticeable at Maputo; early-morning southwest winds back to the southeast, east, and northeast. The effect of the sea breeze is greatest between 1100 and 1500L.

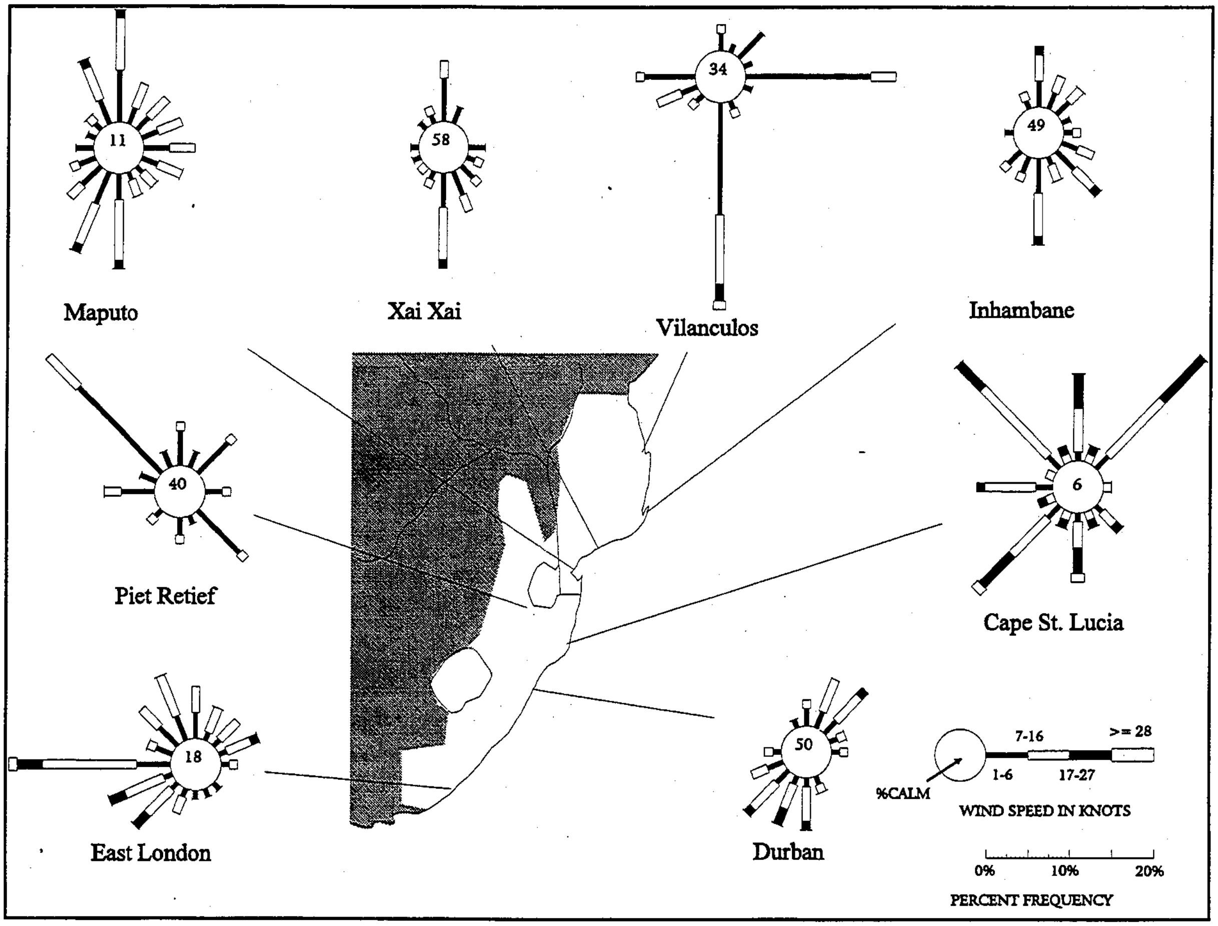



**Figure 6-14. July Surface Wind Roses.**

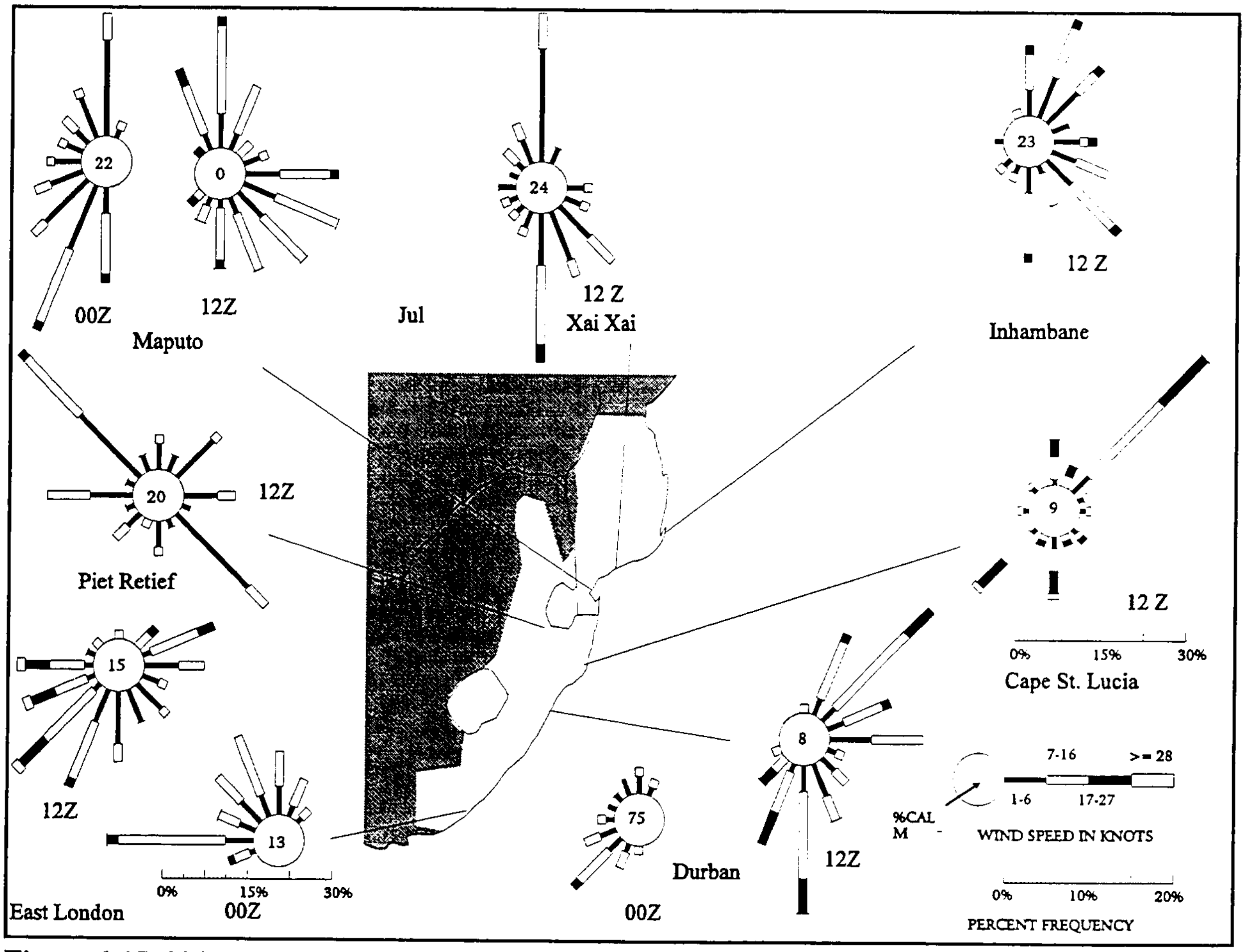



**Figure 6-15. 00Z and 12Z Surface Wind Roses for July**. Note that 00Z data is not available for all stations.

**Winds Aloft.** Figure 6-16 shows the upper-air wind roses for July. The 850-mb winds show high variability due to the region's location with respect to anticyclonic circulation centered in the area.

The Subtropical Jet, farthest north and strongest during this season, is reflected in the 700-300 mb wind roses.

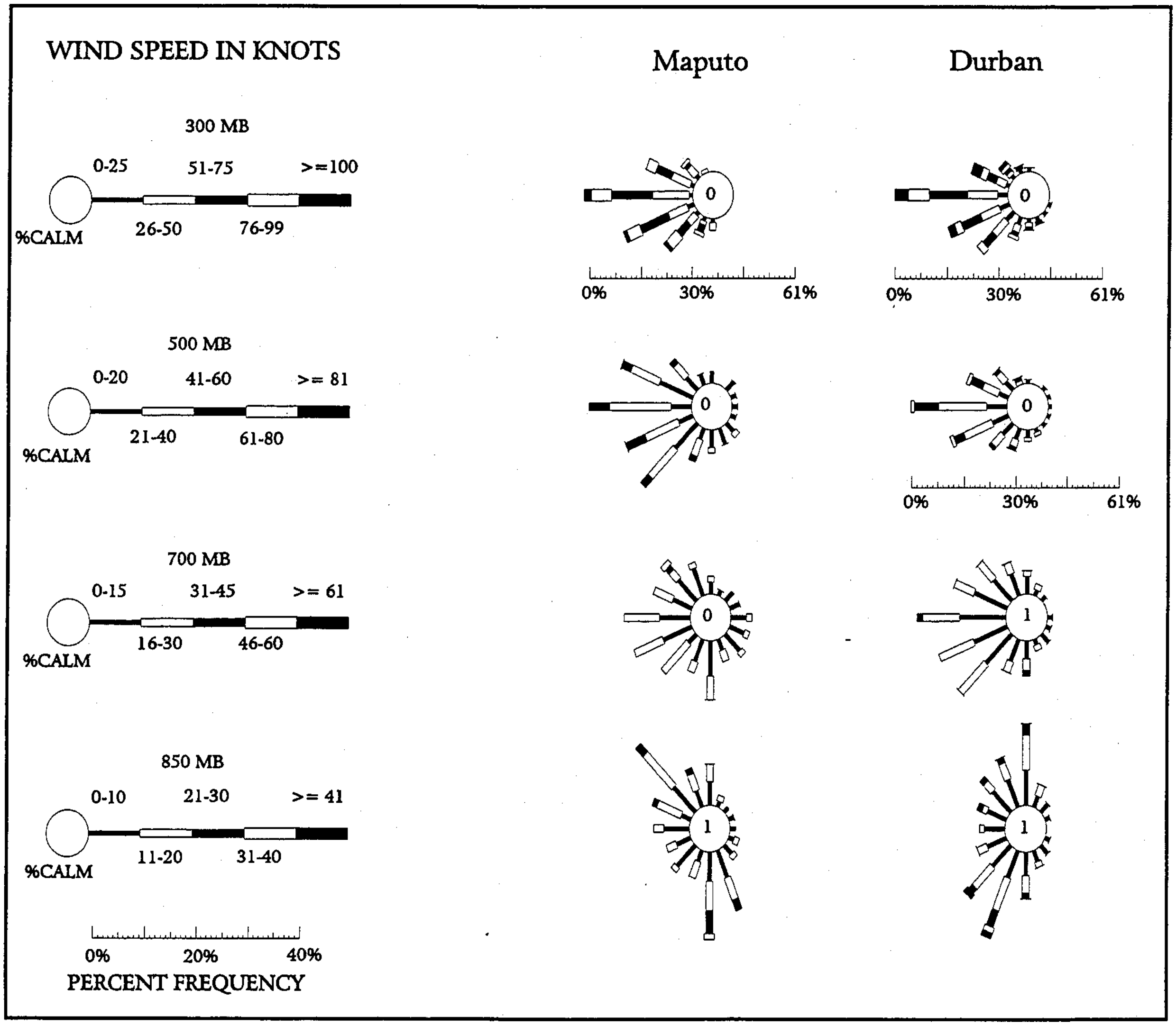



**Figure 6-16. July Upper-Air Wind Roses.**

**Precipitation**. As seen in Figure 6-17, most of the area averages around 10 mm of precipitation during July. Only a few coastal areas receive 50 mm. Cape St. Lucia receives nearly a quarter of its annual rainfall during the dry season. At East London, the proportion is higher; 2/5 of the total there falls in the dry season.

In the interior, the contrast between the wet season and the dry season becomes more pronounced. June to August is especially dry along the coast near Durban and in the northern interior, where the average for the 3 months is about 50 mm, less than 5% of the annual total.

Pre-frontal rainshowers are common with cold fronts. Onshore flow in advance of the following high, combined with orographic lifting, usually produces drizzle. Thunderstorms often follow a cold-air outbreak. The cold maritime air behind an eastward-moving cold front passing over the warm Agulhas Current results in instability that causes lines of towering cumulus and thunderstorms over immediate coastal waters, especially over the southeastern coastal waters from Port St. Johns northward along the coast.

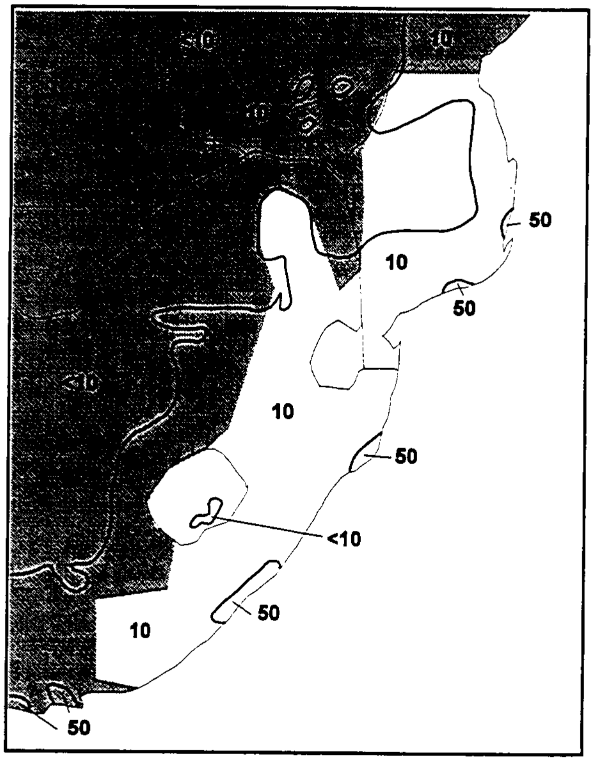


**Figure 6-17. July Mean Precipitation (mm).**

Snow falls about five to nine times a year, most frequently in June and July. It is usually confined to the high mountain ranges (above 3,000 meters). Accumulations are small.

As seen in Figure 6-18, most areas have 5 or fewer rain days a month. Higher frequencies occur along coastal areas due to coastal lows and fronts.

**Thunderstorms** occur on only a few days a month, mainly caused by frontal systems—see Figure 6-18. Thunderstorm bases can be as low as 500 feet, while tops can exceed 30,000 feet.

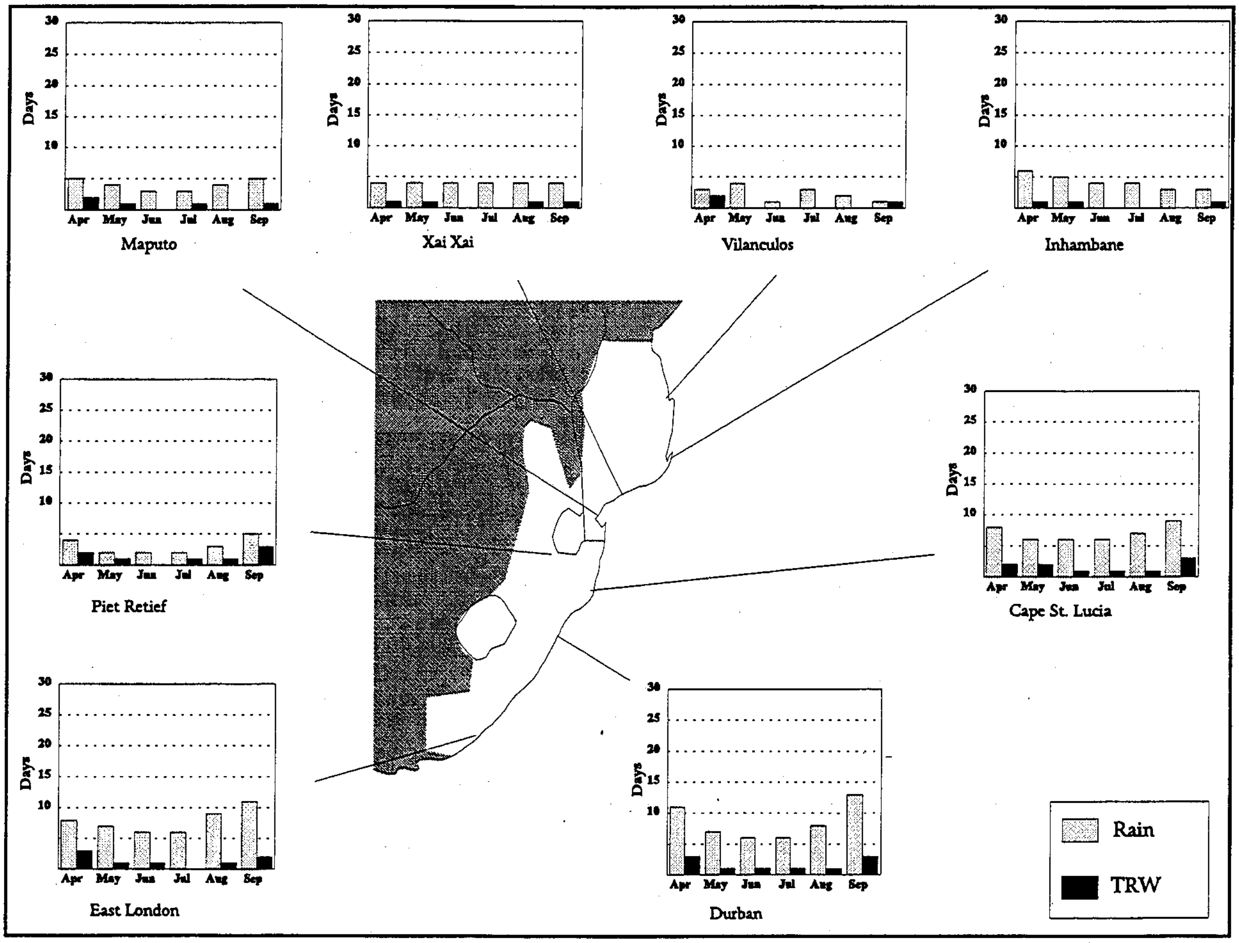



**Figure 6-18. Dry-Season Mean Monthly Rain and Thunderstorm Days.**

**Temperatures**. Coastal areas are generally mild, but temperatures decrease rapidly with elevation along the escarpment (see Figures 6-19 and 6-20).

The earliest and latest appearances of frost are usually in the higher valleys on the edge of the escarpment. The earliest frost (before 10 April) is usually in Lesotho. Temperatures are below freezing 20 to 25 times during July in Lesotho and on the edge of the escarpment.

Extreme lows in the lowlands are in the single digits, while extremes in higher elevations are likely to be around -10 to -15° C. Extreme highs are in the mid 30s ° C, probably caused by berg winds.

**Figure 6-19. July Mean Maximum Temperatures.**

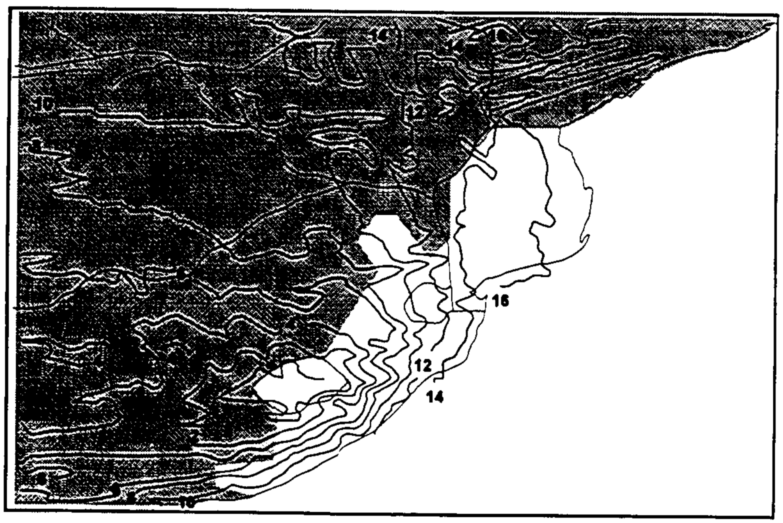


**Figure 6-20. July Mean Minimum Temperatures.**

**Other Hazards.** The heaviest sea swells come from the south and southwest. They are most frequent in the dry season, when a moderate or heavy swell can be expected on about 6 days in 7. The probability of a heavy southwesterly swell is much greater south of the 30th parallel. A heavy southwesterly swell is common between Durban and East London.

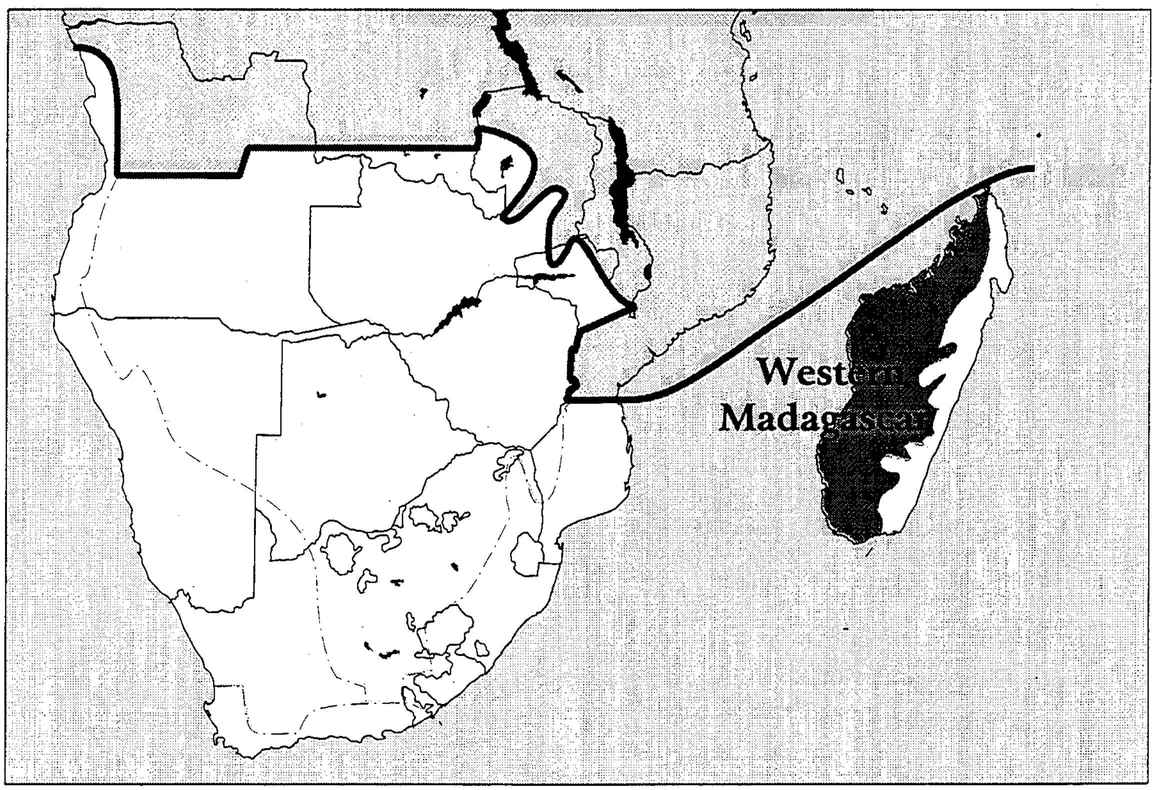
There is fairly close agreement between the directions of the wind and the swell, except inshore where northeasterly winds and rough seas may coincide with a southeasterly swell. This combination is responsible for the bad anchorage outside Durban harbor, and occasional difficulty in entering the harbor.

Rough seas generally accompany southwest winds which, blowing against the Agulhas current, raise a steep breaking sea that increases rapidly as the wind strengthens. The highest and most dangerous seas occur near the 100-fathom line. With northeast winds, the seas increase more gradually, usually becoming rough only during a strong gale.

# Chapter 7

## WESTERN MADAGASCAR

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for the western portion of Madagascar, an area that occupies about two-thirds of the island. The eastern coastal plain of Madagascar below about 600 meters is described in Chapter 8.



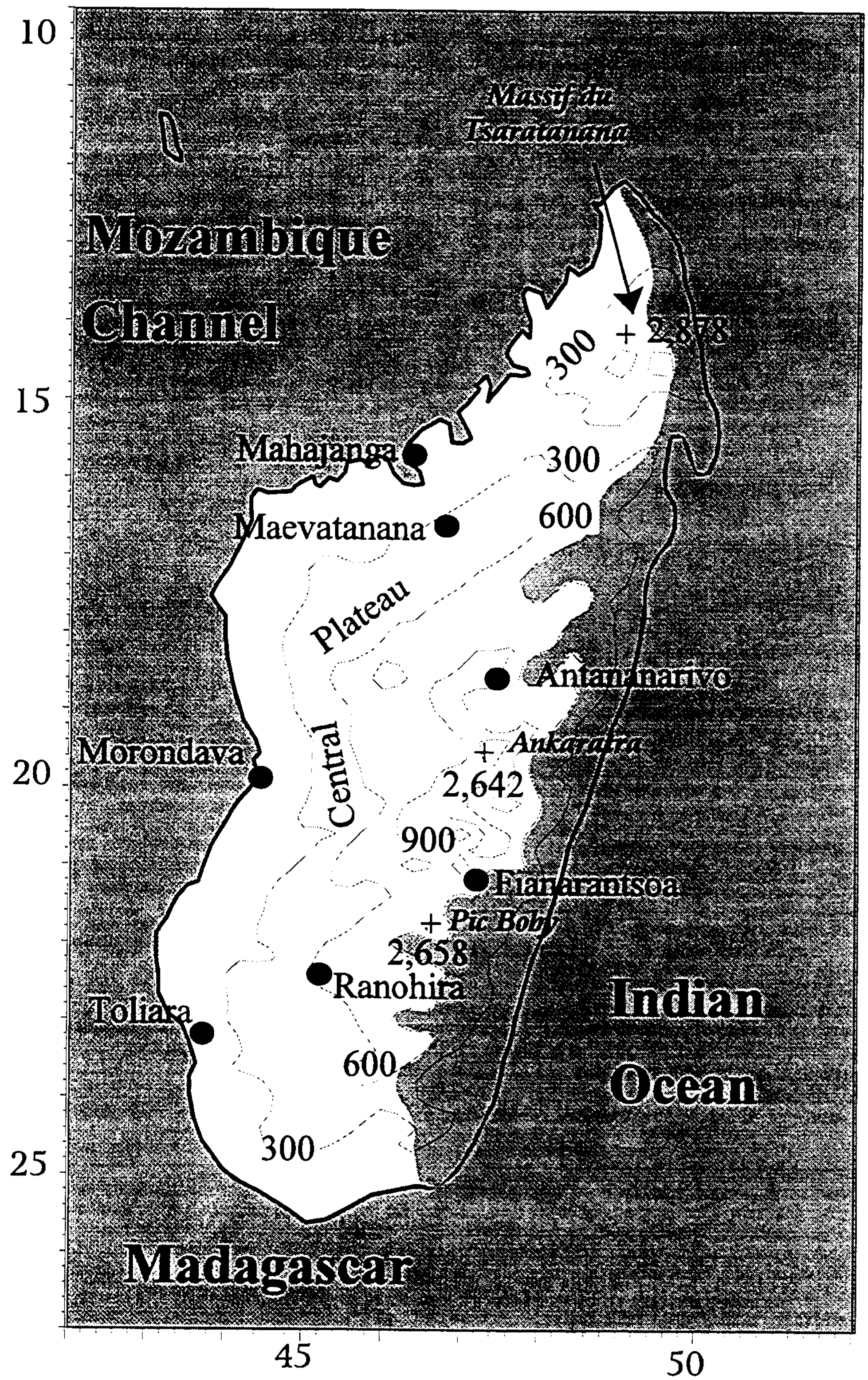



**Figure 7-1. Western Madagascar.**

# WESTERN MADAGASCAR GEOGRAPHY

**Major Terrain Features.** Madagascar, the fourth largest island in the world, lies in the southwestern Indian Ocean, separated from the southeast coast of Africa by the 800-km-wide Mozambique Channel. From northeast to southwest, Madagascar extends about 1,570 kilometers. At its widest point, the island is 570 kilometers wide. Western Madagascar consists of all of the island except the eastern coastal area below about 600 meters (see Figure 7-1).

Western Madagascar's eastern boundary is marked by the steep slopes of the central plateau, which lie at about 600 meters elevation. The boundary extends westward across the mountains of the central plateau, then down the western slopes to the Mozambique Channel, where it ends at the generally straight coastline. The central plateau dominates the high central part of the island. Three mountain ranges rise to more than 2,500 meters at certain points and form a spine running the length of the island from northeast to southwest. In the north, the Massif du Tsarantanana (2,878 meters) is the highest point on Madagascar. In central Madagascar, the Ankaratra is a vast volcanic formation with a summit at 2,642 meters. Farthest south is the enormous granite Andringitra; its summit (2,658 meters) is Pic Boby.

The western plain consists of terrain that slopes gently from the central plateau toward the Mozambique Channel in a succession of hills and valleys. A large series of valleys converges in the northwest at the port of Mahajanga. Small dunes line most of the coast.

**Rivers and Drainage Systems.** Many short and torrential rivers drain the eastern face of the central plateau of Madagascar; they discharge into coastal lagoons or directly into the sea along the east coast. Many longer and wider rivers cross the central plateau westward toward the Mozambique Channel. They carry rich sediments into the western plains and form fertile valleys.

**Vegetation.** Although Madagascar once was covered with evergreen and deciduous forest, those trees are nearly gone due to slash-and-burn farming methods; forests now cover only about 10 percent of the island, mainly on the steep eastern slopes of the central plateau bordering the eastern coastal plain. Western Madagascar covers about two-thirds of the island, but it contains only about 2% of the forested areas. Prairie grasses, bamboo, and small trees cover most of the western plains. Small mangrove swamps line the west coast. The arid south is covered with thorn trees and other drought resistant plants.

**Crops.** Madagascar's economy is mainly agricultural. Even though only 5-13% of the land is arable, agriculture employs about 75% of the work force. Rice accounts for about half of the agricultural production. Coffee is the leading export, but the country is also one of the world's leading suppliers of vanilla and cloves.

## MAJOR CLIMATIC CONTROLS OF WESTERN MADAGASCAR

**General Climate.** Western Madagascar's climate varies from maritime tropical in the northwest to the more temperate maritime in the central plateau. The southwest is hot and dry.

The Indian Ocean, Mozambique Channel, southeast trade winds, and Northeast Monsoon all influence the climate of Western Madagascar. The South Indian Ocean (Mascarene) High, the South African High, and the Mozambique Channel low/trough help determine the extent of the influence of the Northeast Monsoon, the southeast trade winds, and polar outbreaks from the south. These semipermanent features provide steering for the four main meteorological features that affect the weather in Western Madagascar; these features are:

**The Southeast Trades.** These persistent winds form on the south side of the South Indian Ocean High, which, during the warm season, is farther east and weaker than in the cool season; as a result, the southeast trades are weakest in the warm season and strongest in the cool season. Most of the tropical maritime air reaching Western Madagascar has crossed at least 3,000 kilometers of warm-to-hot Indian Ocean waters. The average relative humidity of this air mass is 75% in February—the annual maximum. This very moist air becomes unstable over Western Madagascar due to topography and thermal effects.

**The Northeast Monsoon.** The Northeast Monsoon affects Western Madagascar in the warm season (mainly from December through March) when the eastward shift of the South Indian Ocean High permits the incursion of the monsoon from the north. This air mass, originally cold, dry continental air from Central Asia, is heated adiabatically and dried as it descends the Tibetan Plateau. Northeasterly flow in the Northern Hemisphere assumes a northwesterly direction after crossing the Equator and becomes very humid while traveling 3,000 kilometers over the Indian Ocean, one of the warmest oceans in the world. The relative humidity of this air mass averages 75 to 80%, but it only affects Western Madagascar when the NET crosses the island.

**The Near Equatorial Trough (NET).** The NET, a monsoon trough that lies over Western Madagascar from December to February, causes more cloudiness than the southeast trades alone. The NET represents the convergence of the monsoon air mass with the maritime tropical air mass carried by the southeast trades. The resulting instability causes increased thunderstorms and showers in the northern half of Western Madagascar during this period.

**Polar Outbreaks.** The position of the South Indian Ocean and South African highs control the incursion of polar disturbances into Eastern Madagascar from the south. These Atlantic air masses are rapidly modified as they move along the eastern coast of Madagascar. They assume the characteristics of a cold front, pushing the warmer Indian Ocean air ahead of them, and mixing it as they move northward. The relative humidity is 80 to 85% throughout the air mass. Storms are possible year-round, but they occur mostly during the cool season (May through October).

**Land/Sea Breezes.** Land/sea breezes are significant along the coast of Western Madagascar, especially during the warm season.

**Tropical Cyclones.** Tropical cyclones are a threat to Western Madagascar from December through March, but especially during January and February. Two to three tropical cyclones a year affect the area, but as many as five are possible. These storms mostly develop in the southwest Indian Ocean northeast of the Mascarene Islands between 5 and 10° S. Steering of the tropical storms by the south Indian Ocean High brings them toward Madagascar from the northeast. As they approach the island, they usually curve to the southeast. When this happens, they often move away from Madagascar without touching land. Occasionally, a tropical cyclone develops in the Mozambique Channel and affects Madagascar as it moves east or southeast. These storms are weaker than those that form over the Indian Ocean, but they still have a major effect on the area.

**Low-Level Jet.** In February, a clockwise gyre often develops in the low-level flow over the southern Indian Ocean southeast of the NET. As the NET retreats from Madagascar northward in March and April, this low-level wind band gradually moves northwestward and strengthens, crossing the northern tip of Madagascar. Once it crosses eastern Africa over Somalia (April to May), it is known as the Somali jet (see Chapter 2). In June and July, the jet continues to strengthen; it becomes quasi-stationary through August, when the clockwise gyre moves southeastward and weakens through October as the northwest monsoon arrives in the area. Jet wind speeds average 20 to 40 knots over Madagascar.

**General Weather**. Warm-season weather in Western Madagascar varies by geographic location. The northwest is cloudy, rainy, and hot. The central plateau is also cloudy and rainy, but temperatures are more moderate. The southwest is clear-to-partly cloudy, dry, and hot.

Several factors are responsible for this wide variation over the region. These include the southeast trade winds, tropical cyclones, the Northeast Monsoon, polar disturbances, and local topography. The southeast trade winds dominate, but tropical cyclones, the northeast monsoon, and polar disturbances can overpower their influence. Their relative strength compared to the strength of the trade winds is determined by the strength and position of the semipermanent meteorological features; for example, the position and strength of the South Indian Ocean High determine the strength of the southeast trade winds. The South Indian Ocean High also controls the extent of the incursion of the Northeast Monsoon and polar disturbances over Madagascar.

**Trade Winds** are a major weather producer in Western Madagascar the year-round, although less so in the warm season than in the cool season. The mean direction is nearly perpendicular to the eastern coast. The trajectory over the warm water of the Indian Ocean helps deliver plenty of moisture to the central plateau. Pushed by the trades, the moisture-laden air ascends the steep slopes at the region's eastern border as well as the mountain slopes in the center of the plateau. As it rises, it cools and becomes unstable. As a result, more rain falls east of the mountains in the central plateau than west of them.

**The Northeast Monsoon** affects the north, especially near the northwest coast. The South Indian Ocean High weakens and moves southward during the warm season, allowing the Northeast Monsoon to push farther south than in the cool season. From December to March, the Near Equatorial Trough (NET), where the Northeast Monsoon converges with the southeast trade winds, often lies across northern Madagascar as a monsoonal trough (see Figures 2-6a, 2-6c, and 2-6g in Chapter 2). The additional moisture carried into the area by the Northeast Monsoon, along with the instability caused by the NET, causes more frequent showers and thunderstorms in the north.

**Tropical Cyclones** are a threat to Western Madagascar, particularly during January and February. Two to three tropical cyclones a year affect the area from December through March, but as many as five are possible. These storms are weaker than those that form over the Indian Ocean, but they still have a major effect on the area.

**Polar Lows** and their associated frontal systems are rare during the warm season; they usually stay south of Madagascar. If they do affect Madagascar, they rarely go north of 25° S. For example, in one 6-year period, only one front affected southern Madagascar during January and February. Earlier and later in the season, fronts are more frequent because their associated lows track farther north.

**Sky Cover.** Skies are generally cloudy in the northwest and on the central plateau, where ceilings occur 60 to 70% of the time or more in January (Figure 7-2). Ceiling frequency is about 10 to 20% lower at the beginning and end of the warm season. Ceilings are most common in the afternoon. Early morning skies are generally clear to partly cloudy, but they become partly cloudy to cloudy as cumulus forms during the morning with bases at 2,000 to 3,000 feet. Thunderstorms with bases at 1,500 to 2,000 feet form later in the day. In the vicinity of the NET, broken altocumulus and altostratus extend from 8,000 feet to 16,000 feet; these clouds can last 2 to 3 days, but they do not prevent the formation of the afternoon thunderstorms.

Figure 7-3 shows that the frequency of ceilings below 3,000 feet is lowest along the west coast, where ceilings are mostly due to middle clouds, as mentioned above. Low ceilings are much more common over the central plateau, where it's cloudier in the morning due to a higher incidence of night and early morning fog.

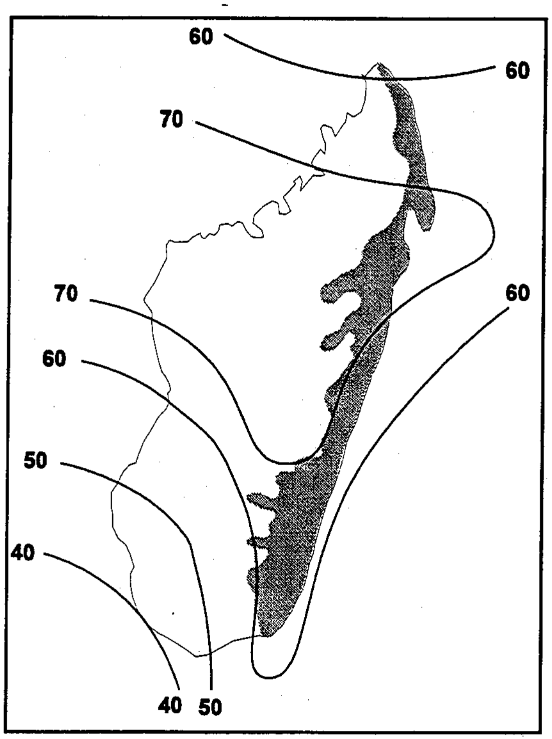



**Figure 7-2. January Percent Frequencies of Ceilings.**

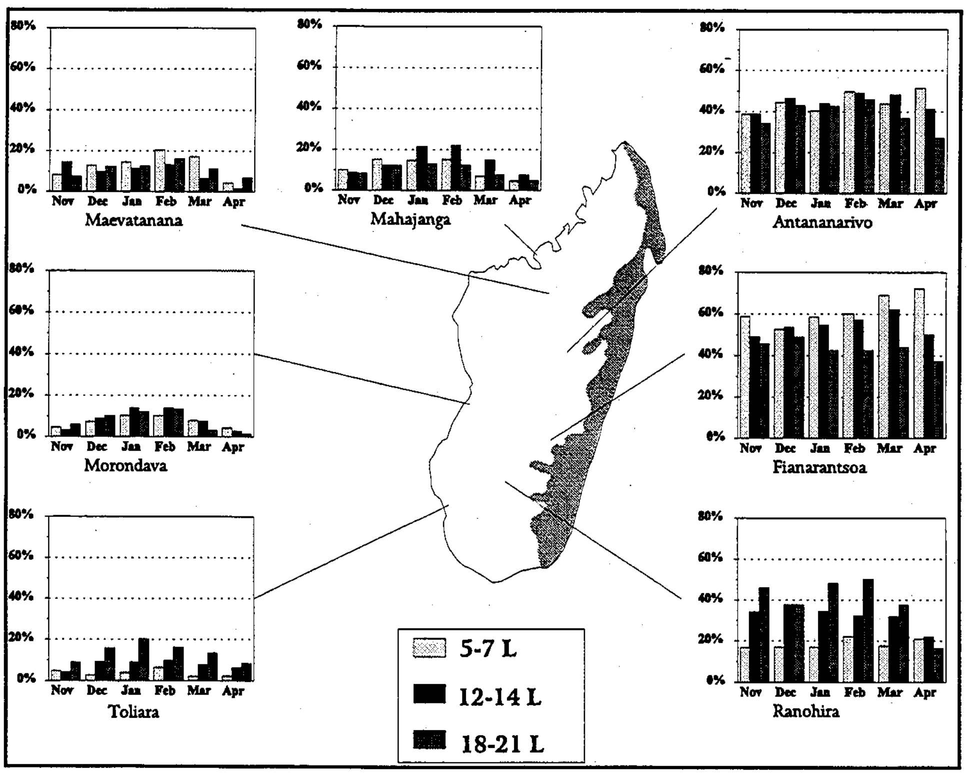



**Figure 7-3. Warm-Season Percent Frequencies of Ceilings Below 3,000 Feet.**

**Visibility.** Generally, good visibility (20-30 kilometers) prevails. Fog is rare except on the central plateau, where it can reduce early morning visibility; Fianarantsoa reports fog as much as 30% of the time in the morning.

At other locations, fog and precipitation reduce visibilities to below 4,800 meters no more than 5% of the time (see Figure 7-4), but brief, heavy rainfall can reduce visibility to less than 1 km; torrential rain can lower it to 500 meters or less.

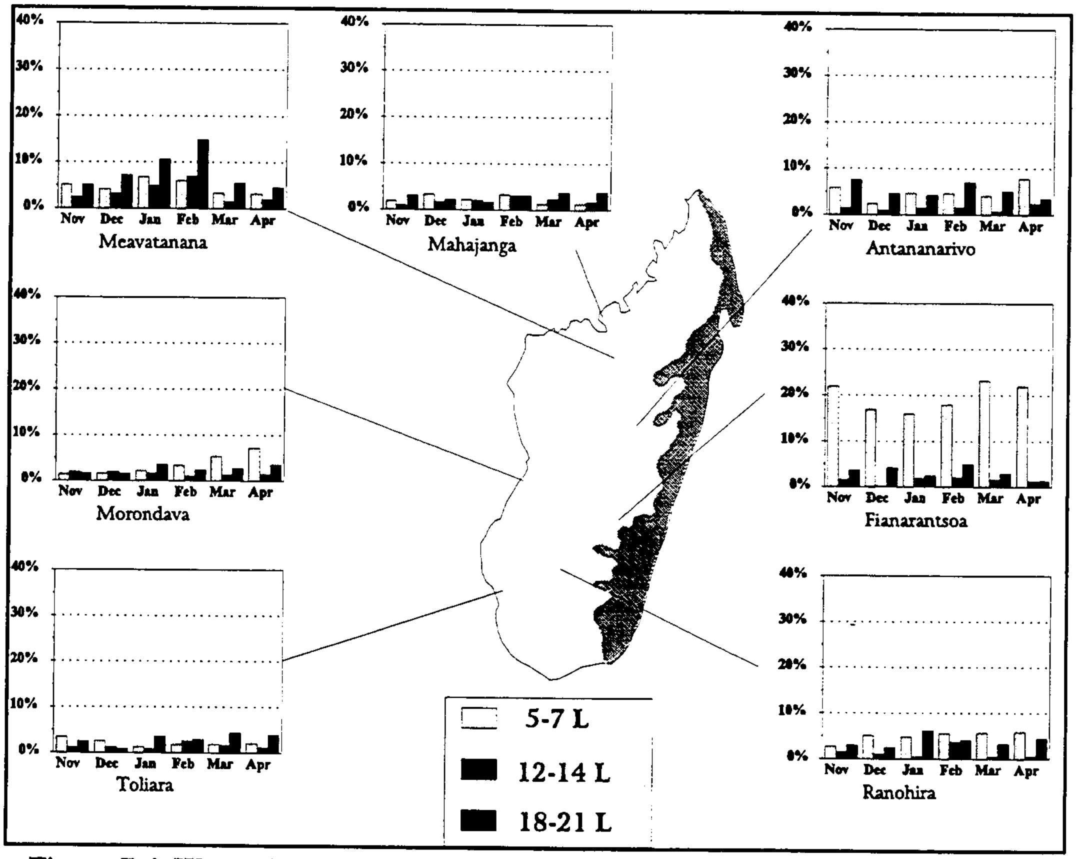



**Figure 7-4. Warm-Season Percent Frequencies of Visibilities Below 4,800 Meters.**

**Surface Winds.** The southeast trade winds prevail most of the year in Western Madagascar, but they are altered by flow against the abrupt rise of the central plateau. Figure 7-5 shows the mean monthly surface winds for January. Prevailing wind directions reflect the trade winds only on the central plateau; they are easterly at Antananarivo, easterly to southeasterly at Fianarantsoa, and northerly to easterly at Ranohira. The land/sea breezes along the west coast are strongest during the warm season. Generally, the sea breeze is first noticeable at about 0900L; it lasts until about 1800L.

The land breeze starts in the evening and lasts for about 10 hours until sunrise. Figure 7-6 (next page) shows January mean surface wind roses at selected locations in Western Madagascar for 00Z (0300L) and 12Z (1500L). Winds are calm or light and variable a high percentage of the time during the night. However, land breezes are noticeable at Mahajanga, Morondava, and Toliara; at 12Z, the sea breeze is well established at these locations. The sea breeze along the west coast is usually so strong that the southeast trade winds cannot overpower it.

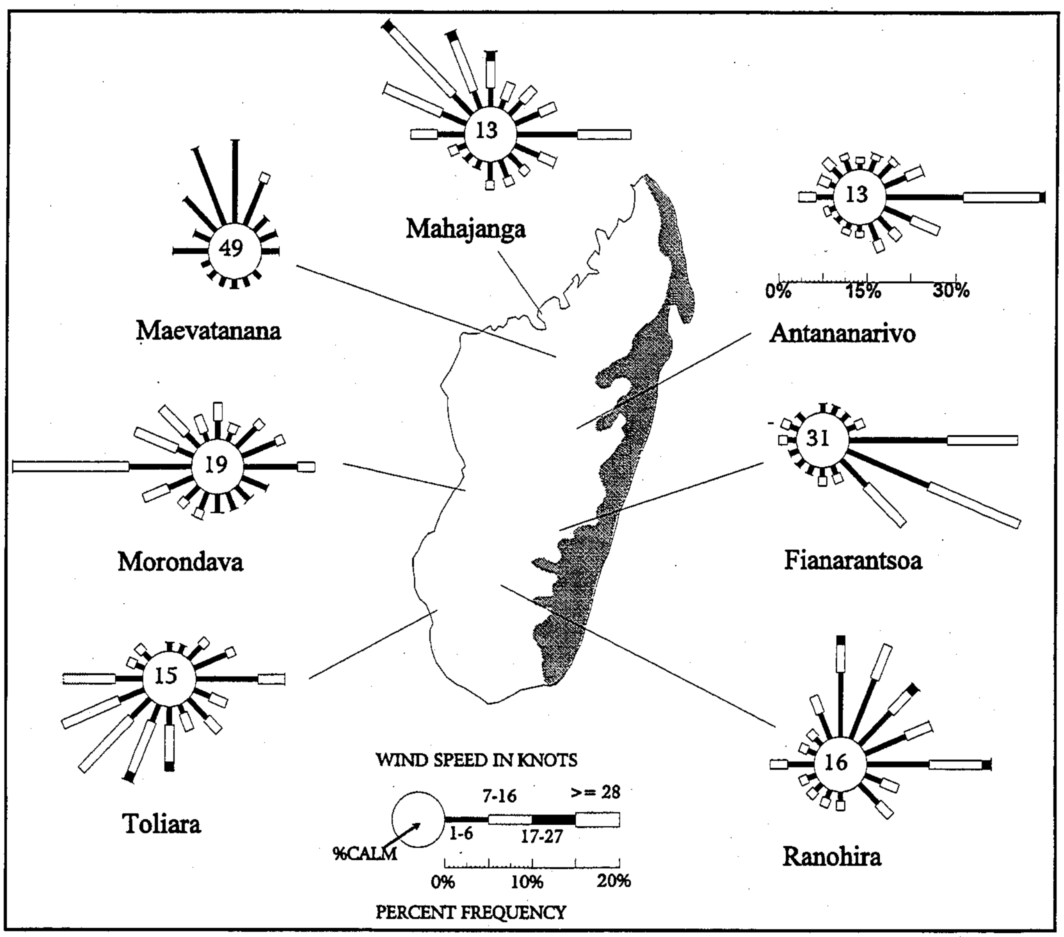



**Figure 7-5. January Surface Wind Roses.**

**Surface Winds, Continued.** The strongest surface winds in the warm season are caused by tropical storms, which occur mainly from December through March. They can cause sustained winds over 75 knots; gusts of 100 to 150 knots are possible.

Although rare in the warm season, cold fronts approaching Madagascar from the southwest can bring strong northwest winds ahead of the fronts to the extreme southwest.

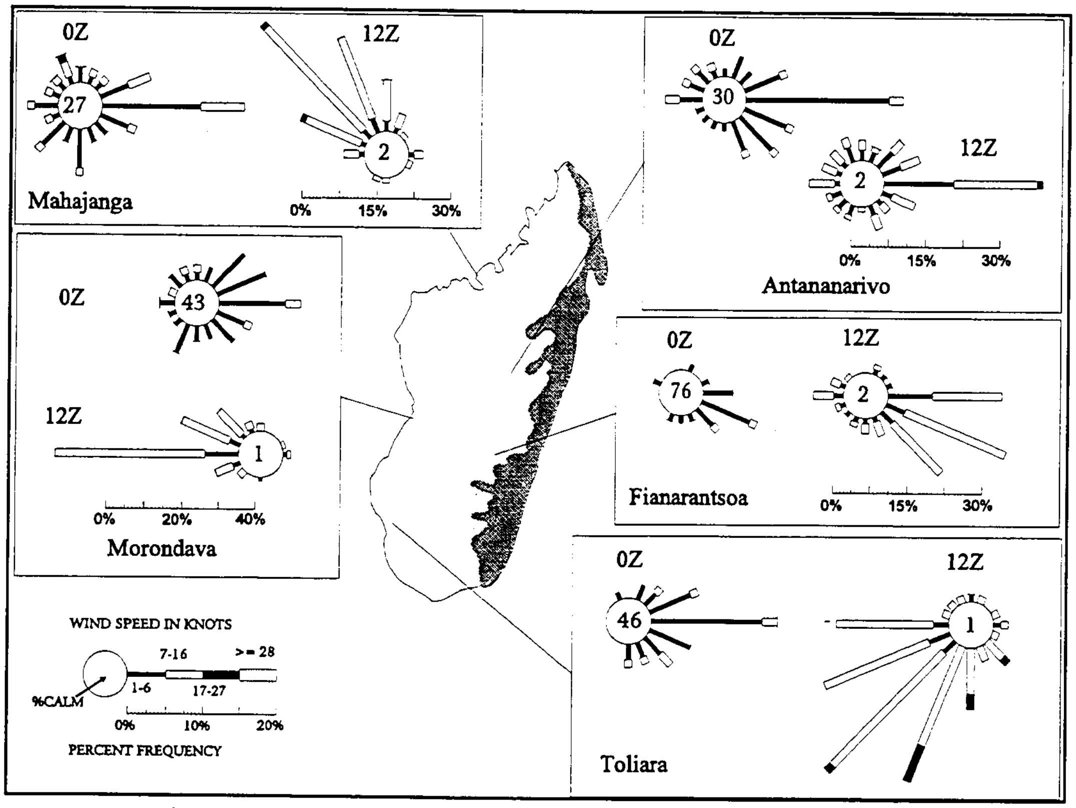



**Figure 7-6. 00Z and 12Z Surface Wind Roses for January.**

**Winds Aloft.** Strong winds aloft are rare over Western Madagascar during the warm season. In the north, southeasterly trade winds persist at lower levels. At about 1,000 meters, the Somali Jet barely touches the extreme northern part of Western Madagascar from February to April. The strength of this low-level jet depends on the strength of the South Indian Ocean High.

Above 2,000-3,000 meters, wind directions are variable due to the alternating influence of the northwest monsoon flow and the southeast trade winds. Over the central plateau, the southeast trades persist at the 850-mb level (see Figure 7-7). Westerlies prevail above the variable mid-level winds. In April, as the warm season changes rapidly to the cool season, stronger westerly winds prevail.

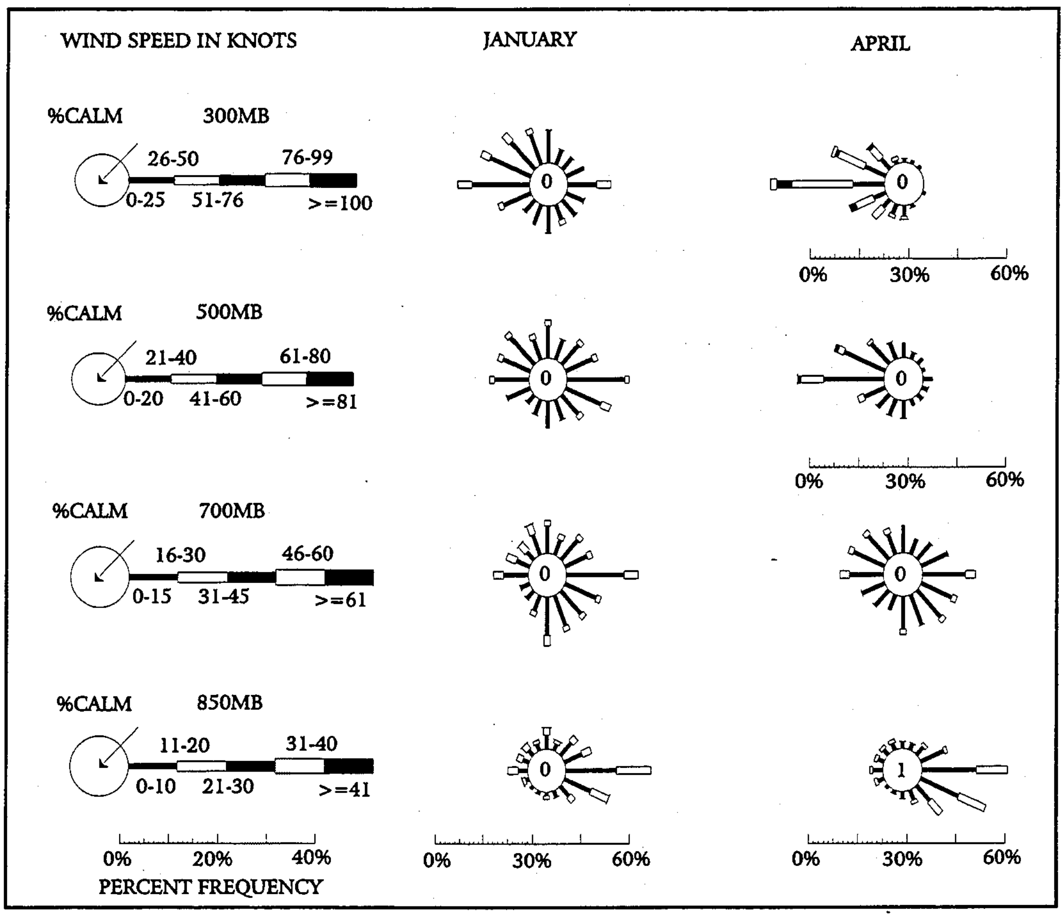



**Figure 7-7. January and April Upper-Air Wind Roses at Antananarivo.**

**Precipitation.** The warm season is also the rainy season in Western Madagascar. Even though the southeast trade winds are weaker than in the cool season, they carry more moisture into the region. Increased evaporation from the hot Indian Ocean surface (26° to over 28° C in January—see Figure 2-2 in Chapter 2) is partly responsible for this. Orientation to the trade winds is also a factor. In addition, convergence of the southeast trades with the northeast monsoon in the NET results in increased instability that causes more showers and thunderstorms over the northern half of the area. Tropical storms can cause more rainfall, particularly during December through March. Total rainfall for the warm season in Western Madagascar ranges from about 1,000 mm to over 2,000 mm. Maximum 24-hour rainfall amounts of over 250 mm to over 500 mm have been recorded with tropical storms. Figure 7-8 shows mean precipitation amounts during January (one of the highest rainfall months) and April.

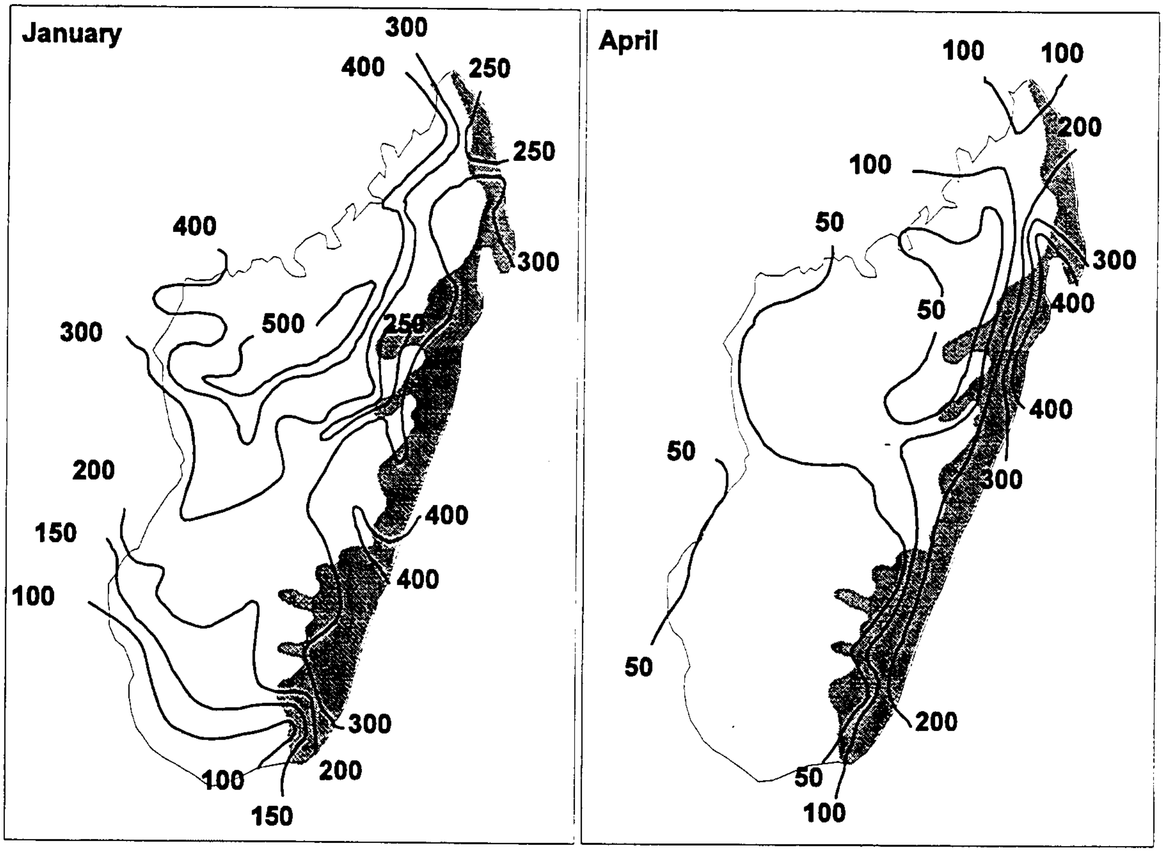



**Figure 7-8. January and April Mean Precipitation (mm).**

**Thunderstorms.** There are more thunderstorms during the warm season than in the cool season. Instability along the NET enhances thunderstorm development and causes most to occur between December and March, but most develop in January. Intense solar heating, combined with less low-level cloudiness along the west coast, helps thunderstorm development as moisture-laden air flows up steep slopes on the region's eastern border.

Thunderstorms form mainly in late afternoon to evening. Duration at a given location is usually 20-60 minutes. Thunderstorms generated by tropical cyclones occur in squall lines, are severe, and can extend up to 40,000 feet. In the north, thunderstorms occur about 8-15 days a month from December to March. They decrease southward to 5 days or fewer a month (see Figure 7-9). Hail is rare in Western Madagascar.

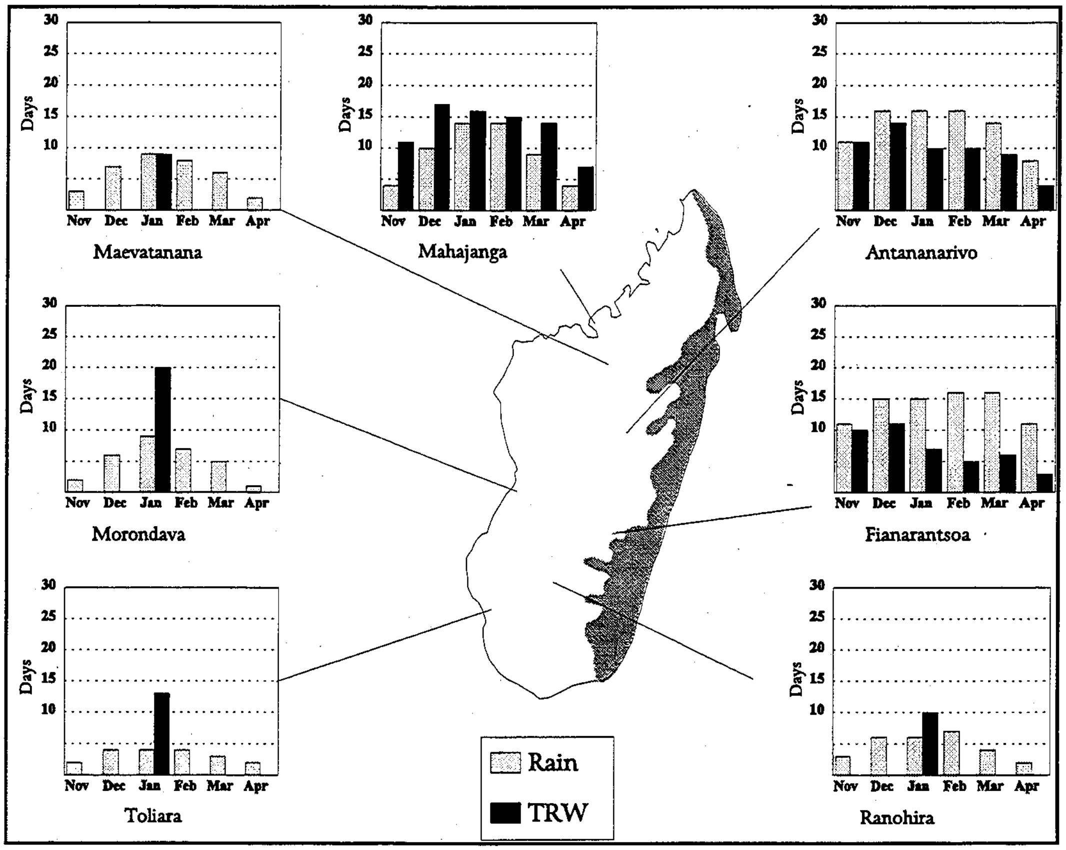



**Figure 7-9. Warm-Season Mean Monthly Rain and Thunderstorm Days.**

**Temperatures.** January is one of the hottest months of the year. It is hottest along the west coast, where there is generally less cloudiness. Temperatures vary from average highs of less than 26° C in the higher elevations on the central plateau to over 30° C near the west coast (see Figure 7-10). Temperatures don't vary much throughout the warm season, but extreme highs of 40° C can occur along the west coast. Average lows in January vary from below 18° C in the mountains to more than 24° C along the west coast. Extreme lows below 10° C are possible at higher elevations due to polar outbreaks, but early or late in the season.

**Other Hazards.** Tropical storms are accompanied by destructive winds, torrential rains, and floods.

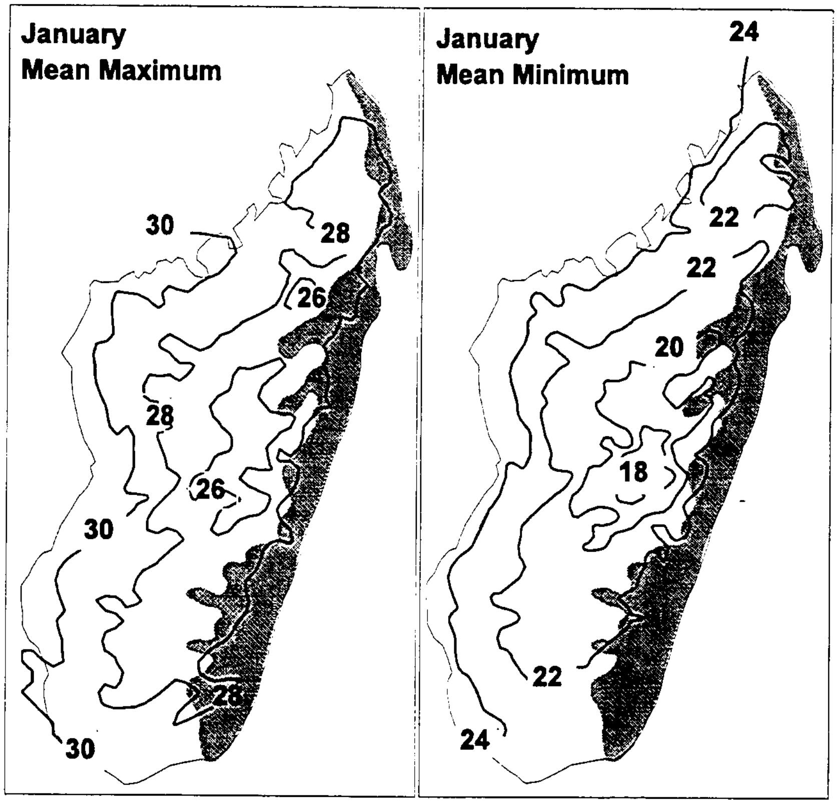



**Figure 7-10. January Mean Maximum and Minimum Temperatures.**

**General Weather.** The South Indian Ocean High strengthens and moves north, keeping the NET north of Madagascar. The South African High, also intensified due to strong radiative cooling, extends eastward to join the South Indian Ocean High. The resulting synoptic weather pattern is fairly stagnant, interrupted only by rare tropical cyclones and polar disturbances.

The southeast trade winds, strongest at this time of year, dominate Western Madagascar's weather. Except for weather associated with an infrequent polar disturbance or rare tropical cyclone, the primary weather controls are topography, the strength of the trades, and trade-wind exposure.

Polar lows and their associated frontal systems move toward Madagascar from the southwest; three or four fronts a season reach as far north as 10° S.

There is less rainfall than in the warm season. Cooler south Indian Ocean water temperatures (22° to 25° C in July) are the partial cause, since less moisture evaporates from the ocean surface and mixes into the air mass below the trade wind inversion.

Most rainfall occurs with orographic lift in the eastern part of the region. The western part of the region is dry due to central mountain rain shadows.

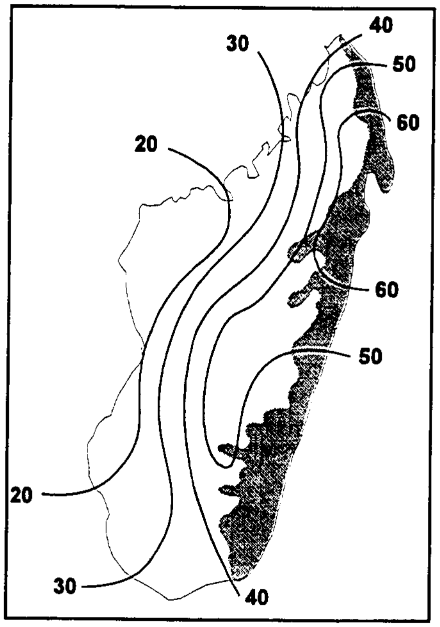



Figure 7-11. July Percent Frequency of Ceilings.

**Sky Cover.** Cloud cover is at its yearly minimum midway through the cool season. Clouds are thickest in the east, where they are caused by orographic lift of maritime tropical air. Cloudiness decreases westward; dissipation starts at the western edge of the plateau due to downslope flow. Ceilings are present less than 20% of the time near the Mozambique Channel in July (Figure 7-11), but they occur over 50% of the time in the northeast, where the trades are strongest. Low ceilings are uncommon except on the Central Plateau (see Figure 7-12), where ceilings are below 3,000 feet up to 80% of the time in the morning and 40% of the time in the afternoon to evening. Morning fog and stratus on the Central Plateau, accompanied by light drizzle, contribute to the high incidence of these ceilings, which can occur with a weakening of the South Indian Ocean High, with a low south of Madagascar, or with the passage of a polar disturbance.

Early morning stratus with bases at 500 to 1,000 feet lifts and dissipates by afternoon. Scattered to partly cloudy skies with cumulus at about 2,000 feet develop as the stratus dissipates; the cumulus doesn't usually penetrate the trade-wind inversion (2,000 to 3,000 meters). In the west, a passing polar disturbance or a sudden strengthening of the trade winds can result in stratocumulus and cumulus ceilings below 3,000 feet, but generally less than 5% of the time.

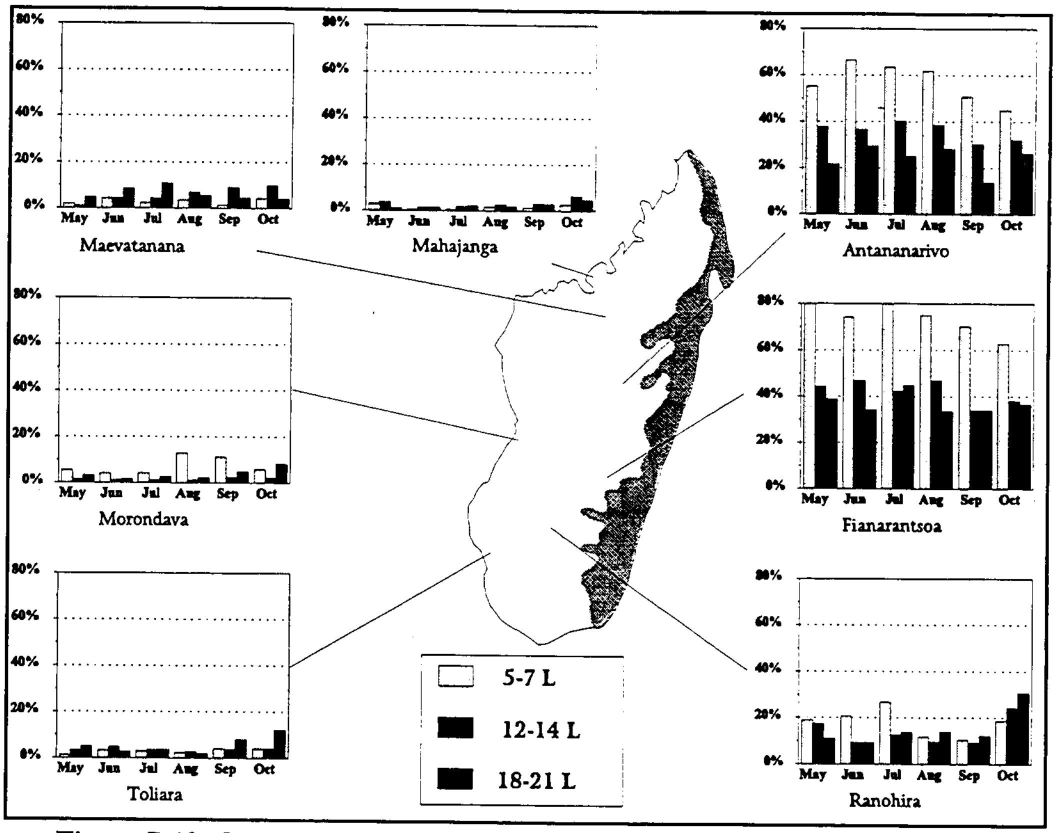



Figure 7-12. Cool-Season Percent Frequencies of Ceilings Below 3,000 Feet.

**Visibility.** Although generally good (50 kilometers or more), cool-season visibility can be reduced by fog, drizzle, or rain showers. Early morning fog and light drizzle on the Central Plateau reduce visibilities to less than 4,800 meters up to 40% of the time at some locations (see Figure 7-13). By mid-to-late morning, visibility improves as the fog dissipates.

Rain showers—sometimes heavy—fall in late afternoon or evening. Visibilities are less than 4,800 meters about 4-6% of the time during the afternoon. Brief, heavy rainfall can reduce visibility to less than 1 kilometer; torrential rain can reduce it to 500 meters or less.

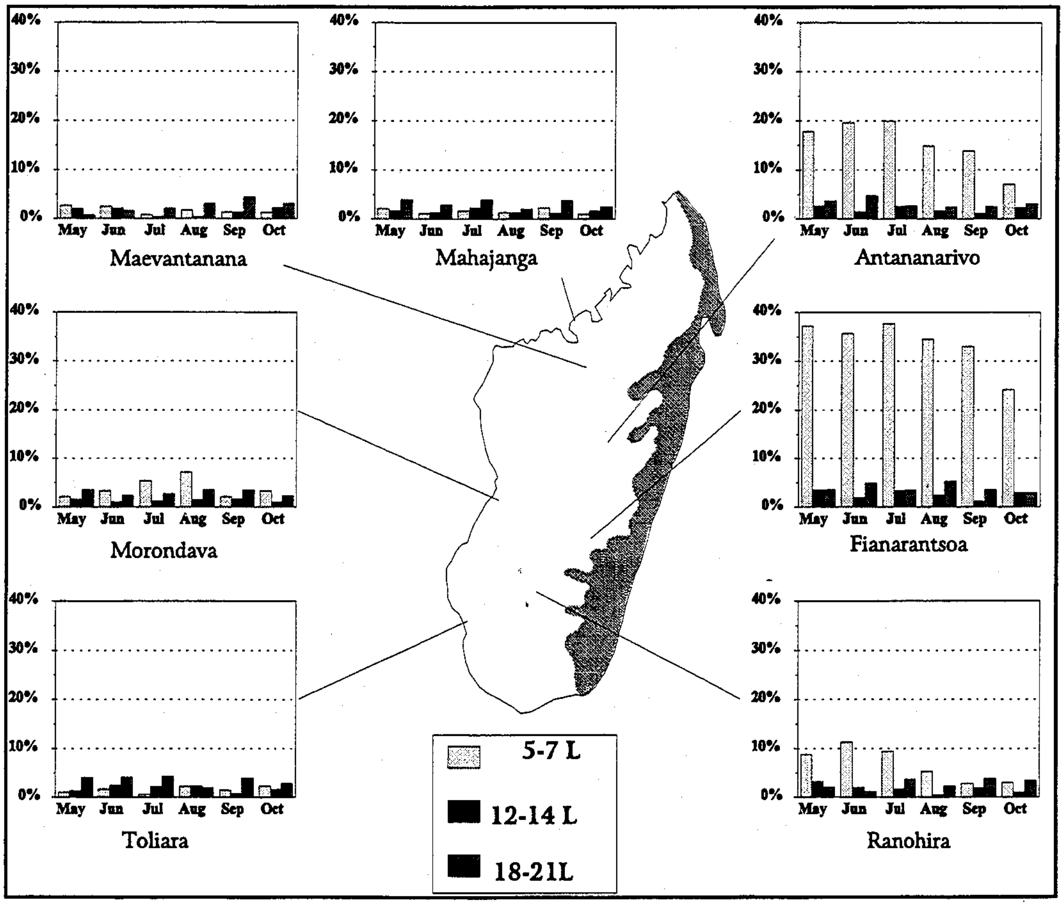



Figure 7-13. Cool-Season Percent Frequencies of Visibilities Below 4,800 Meters.

**Surface Winds.** The southeast trade winds prevail, but they are altered by flow over the mountains and the Central Plateau. Figures 7-14 and 7-15 show mean monthly surface winds for July and October. Generally, the trade winds dominate the surface winds on the Central Plateau, while the surface winds at locations near the Mozambique Channel show the influence of the land/sea breeze.

Figure 7-16 shows mean July surface wind roses at selected locations in Western Madagascar for 00Z (0300L) and 12Z (1500L). Winds are often calm or light and variable during the night, but a land breeze is noticeable at Mahajanga, Morondava, and Toliara.

Land/sea breezes along the west coast are weaker in the cool season than in the warm season due to less intense heating of the land. Generally, the sea breeze is first noticeable at about 0900L; it lasts until about 1800L. The land breeze starts in the evening and lasts for about 10 hours, until sunrise.

Rare tropical storms can produce winds of 65 knots to over 100 knots. Wind gusts of 100 to 150 knots are possible.

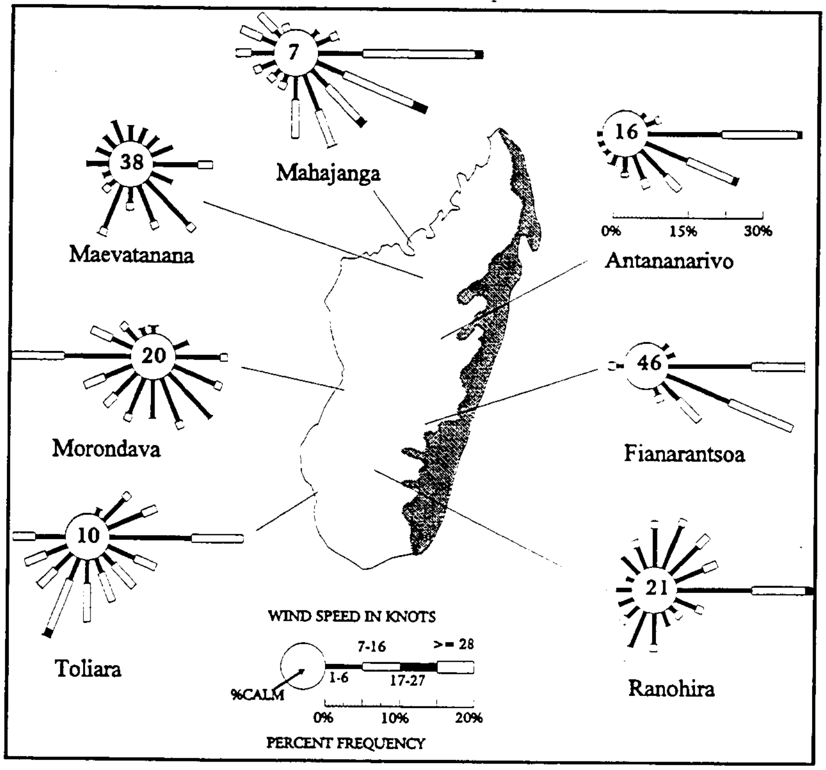



**Figure 7-14. July Surface Wind Roses.**

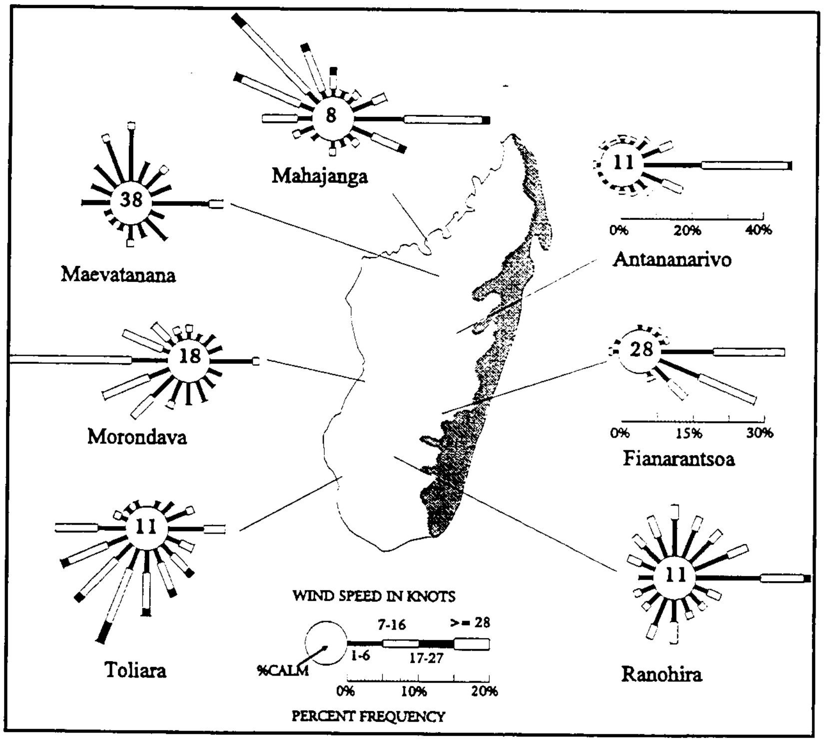



**Figure 7-15. October Surface Wind Roses.**

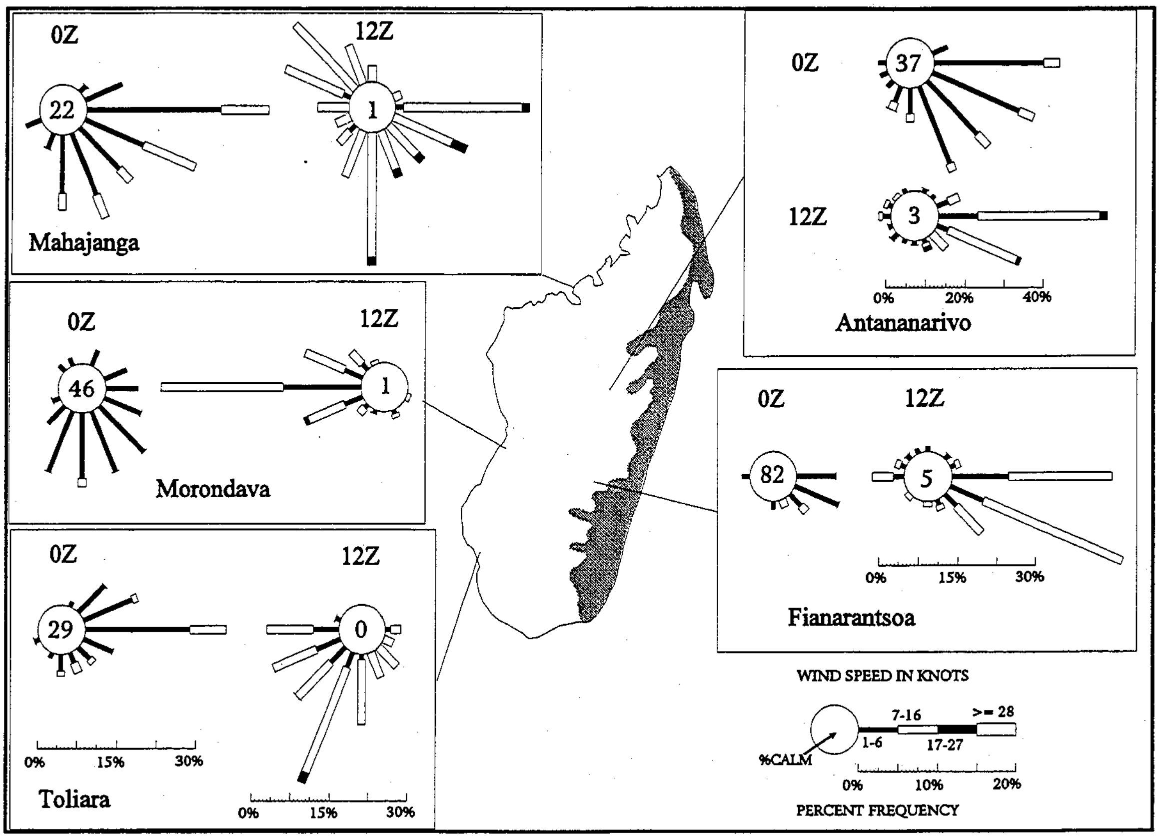



**Figure 7-16. 00Z and 12Z Surface Wind Roses for July.**

**Winds Aloft.** Strong winds aloft are rare over Western Madagascar during the cool season (see Figure 7-17). Below the trade-wind inversion (2,000-3,000 meters), the southeasterly trade winds dominate. Because of the blocking effect caused by the high terrain on Madagascar, the deflected trades are southeasterly in the north, northeasterly in the south, and easterly in between. The Somali jet crosses the northern tip of Madagascar at about 1,000 meters, with average speeds of 20 to 40 knots. Above the trade-wind inversion (2,000-3,000 meters), wind direction is variable until about the 500-mb level, where light westerly winds prevail. Higher in the atmosphere, stronger westerlies prevail. While the mean position of the southern hemisphere subtropical jet is south of Madagascar, it is occasionally far enough north to cause strong winds at 300 mb across southern Madagascar. During July, winds exceed 75 knots about 8% of the time; they exceed 100 knots about 4% of the time.

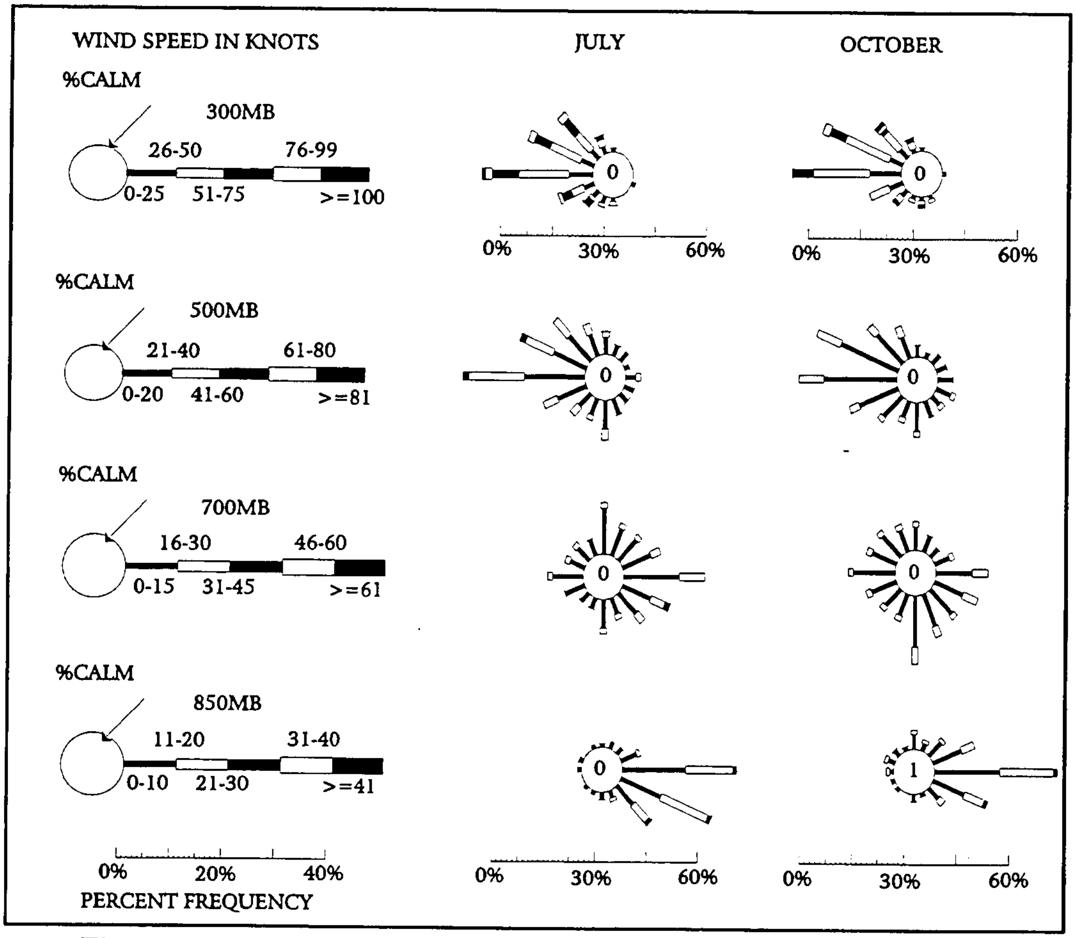



**Figure 7-17. July and October Upper-Air Wind Roses for Antananarivo.**

**Precipitation.** Monthly rainfall ranges from a minimum of 10 mm or less in the west to 100 mm or more in the east (see Figure 7-18). By October, rainfall increases in the northwest as the cool season nears its end. Locations near the Central Plateau have the most days with rainfall, with up to 10 a month (see Figure 7-19). Stations in the west (where it is much drier) experience almost no days with rainfall.

Polar outbreaks can cause snowfall on the highest mountain peaks above about 2,400 meters. Snow melts rapidly.

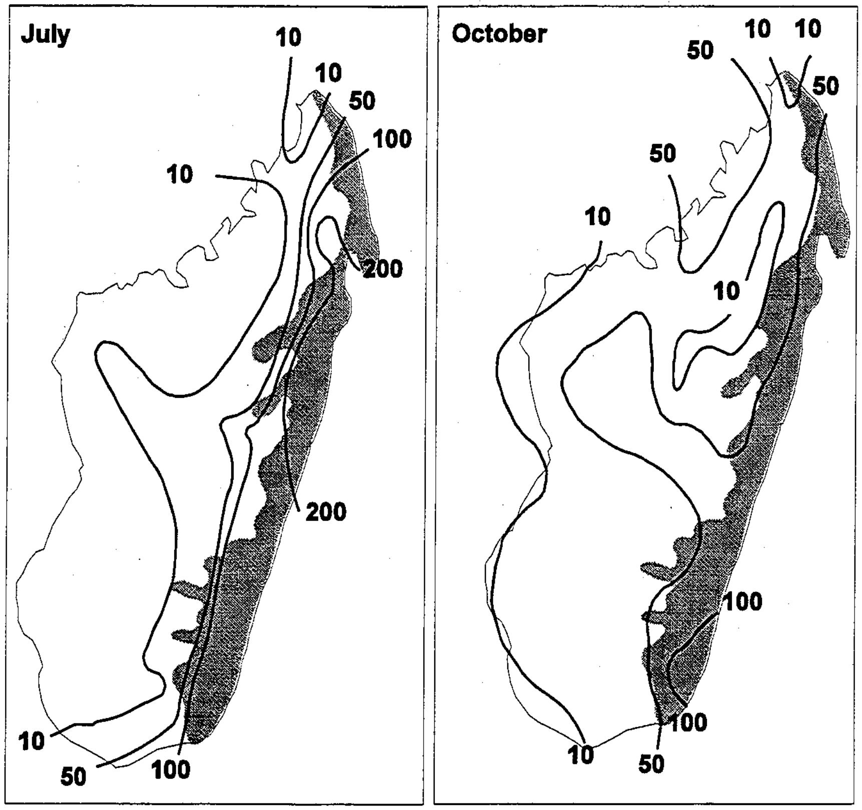



**Figure 7-18. July and October Mean Precipitation (mm).**

**Thunderstorms.** Rare thunderstorms may occur early or late in the season. Air-mass thunderstorms form mainly in late afternoon or evening. Those associated with rare early-season tropical cyclones occur in squall lines, are severe, and can extend up to 40,000 feet. Only Antananarivo and Fianarantsoa have more than 5 thunderstorm days a month (see Figure 7-19). Hail is rare.

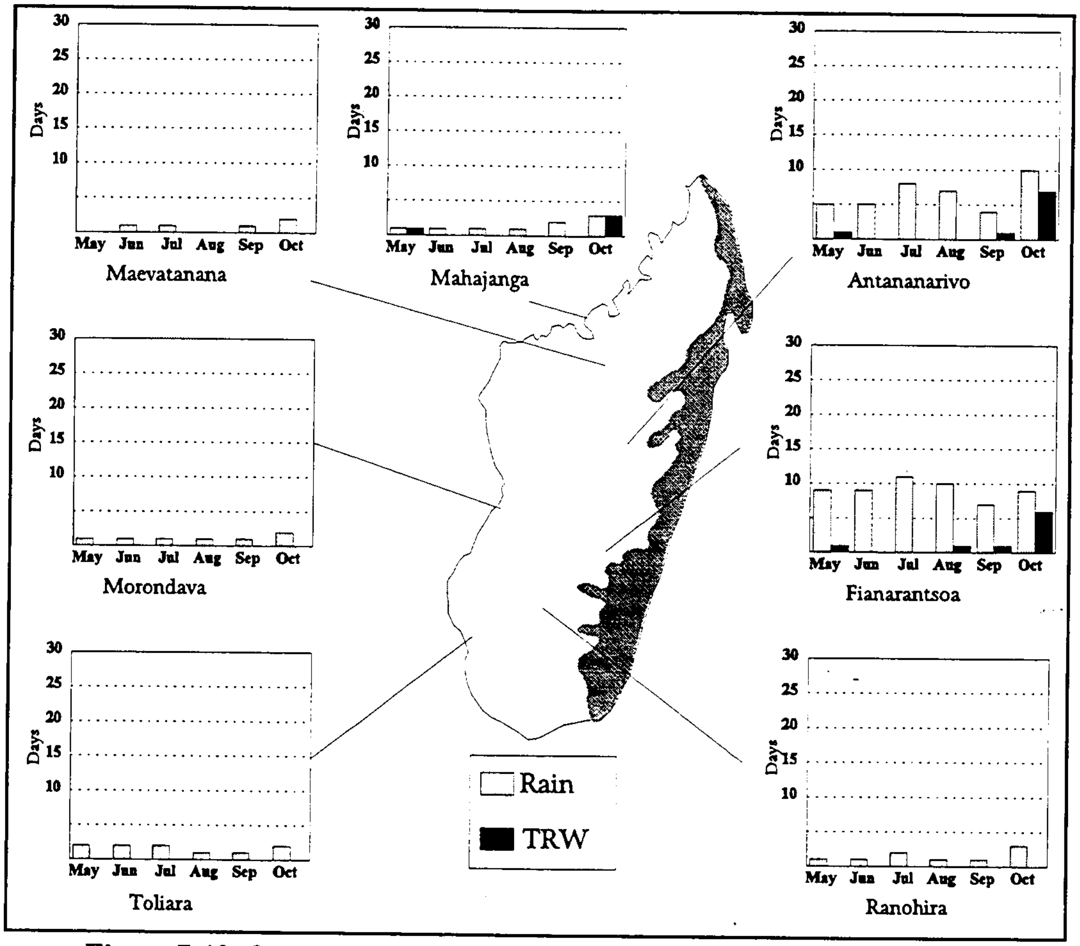



**Figure 7-19. Cool-Season Mean Monthly Rain and Thunderstorm Days.**

**Temperatures.** July is usually the coolest month of the year. Average lows in July are 12° C or less in the mountains, warming to about 20° C in the northwest. Extreme lows near freezing are possible at higher elevations during June and July, generally due to unusually strong polar lows.

Average high temperatures in July range from about 20° C in the mountains to near 30° C in the northwest (see Figure 7-20). Extreme highs of 40° C in the north to 38° C in the south occur in May or October, the warmest months of the cool season.

**Other Hazards.** Although tropical cyclones are rare in the cool season, they can cause destructive winds, torrential rains, and floods.

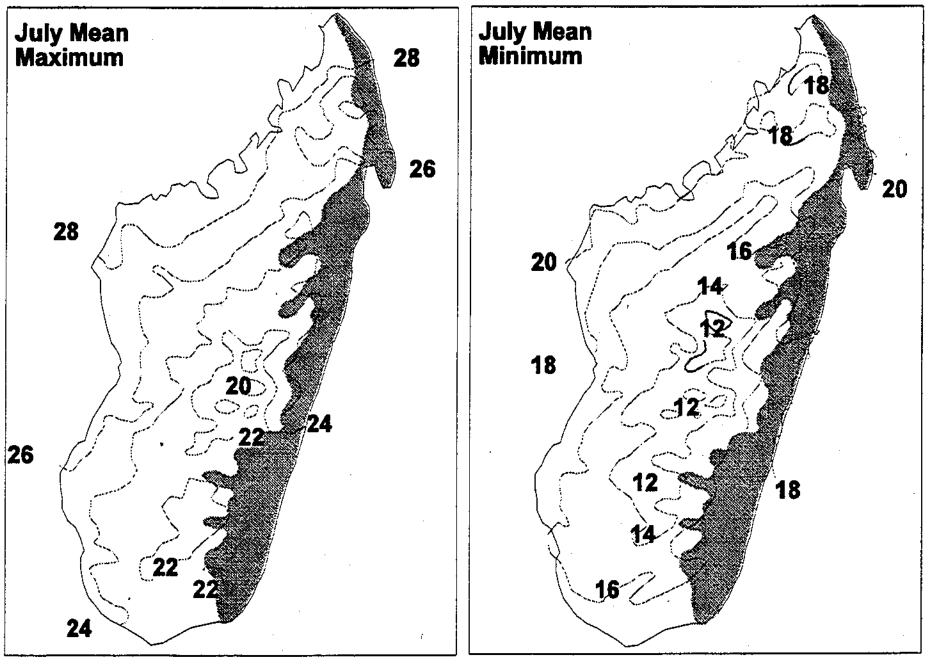
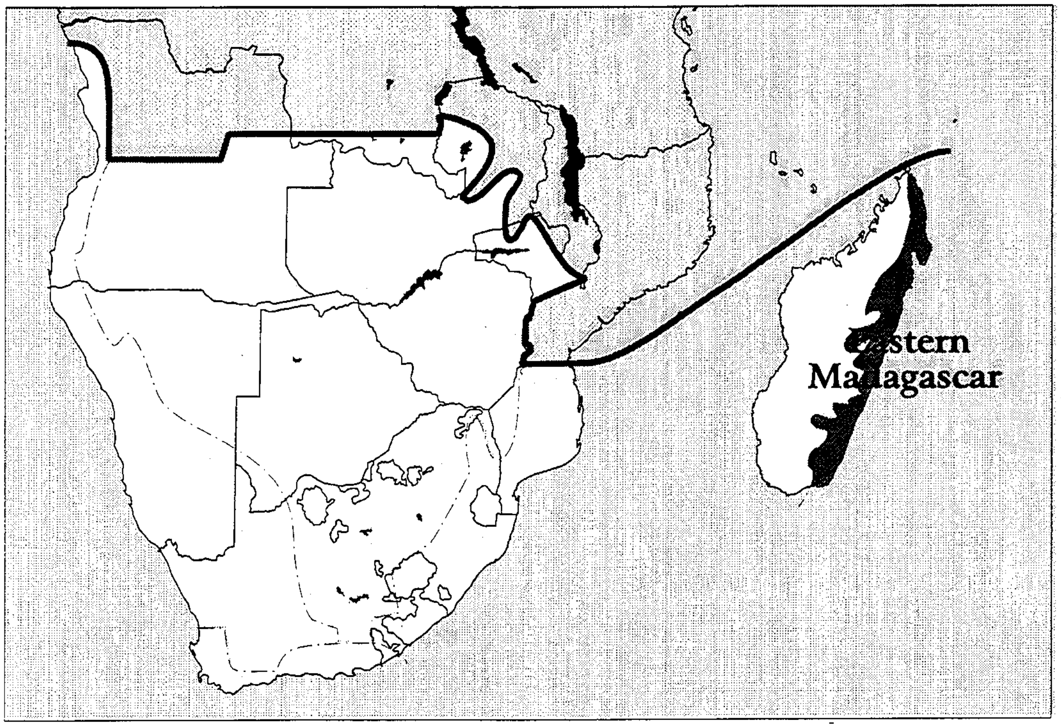


Figure 7-20. July Mean Maximum and Minimum Temperatures.

# Chapter 8

## EASTERN MADAGASCAR

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for the eastern coast of Madagascar, as shown below.



# MAJOR CLIMATIC CONTROLS OF EASTERN MADAGASCAR

**Terrain.** Madagascar, the fourth largest island in the world, lies in the southwestern Indian Ocean. The 800-kilometer-wide Mozambique Channel separates Madagascar from Africa. From northeast to southwest, Madagascar extends about 1,570 kilometers (between 12° and 26° S latitude); at its widest point, it is 570 kilometers wide.

Eastern Madagascar consists of the eastern part of Madagascar below 600 meters elevation. Its main feature is a coastal plain 17 to 33 kilometers wide that borders the Indian Ocean and extends southward from the Bay of Antongil to Tolanaro (formerly Ft. Dauphin). A narrow coastal strip extends northward from the Bay of Antongil to Antsiranana (formerly Diego-Suarez).

The coastal plain has almost continuous lagoons that are linked by the Canal des Pangalanes, an inland waterway that parallels the coast from just north of Toamasina south to Farafangana. The coast becomes very rocky south of Farafangana.

**Rivers And Drainage Systems.** Many short and torrential rivers drain the eastern face of the central plateau. They discharge into Eastern Madagascar's lagoons or directly into the sea.

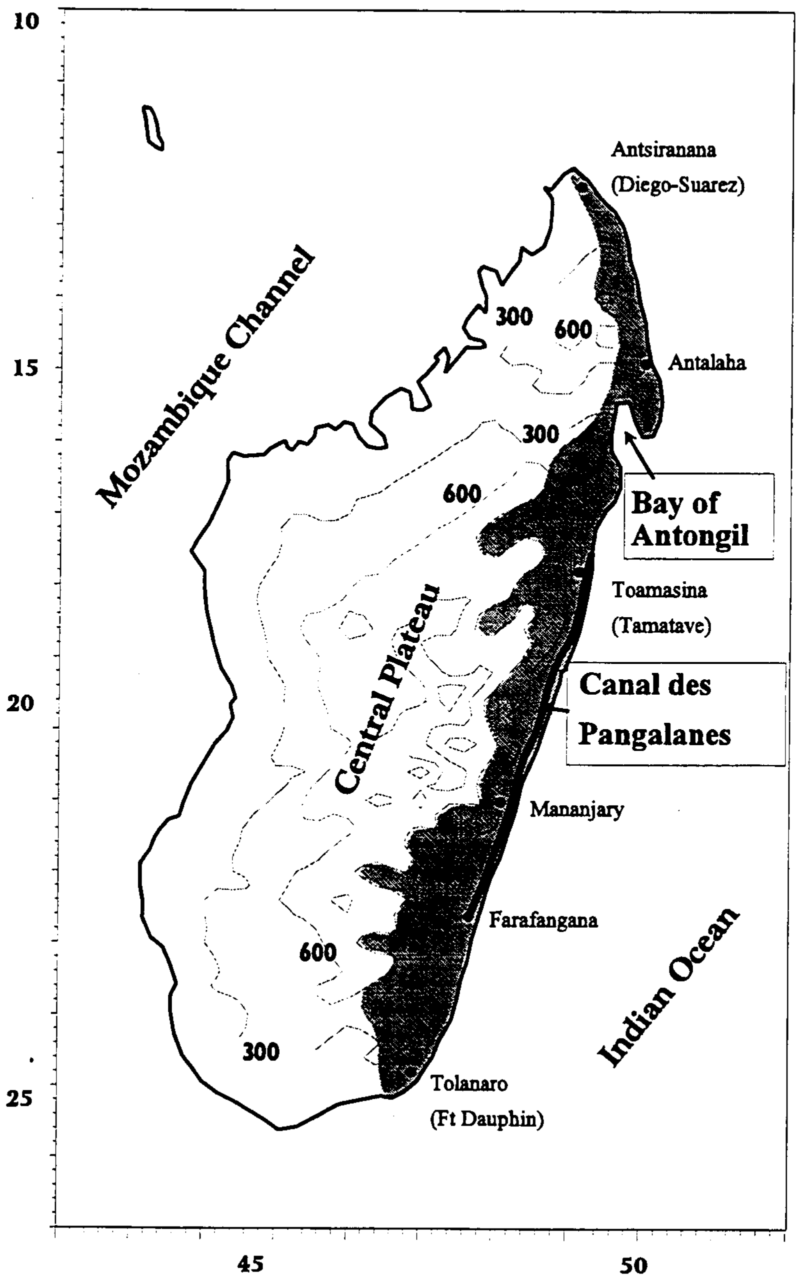



**Figure 8-1. Eastern Madagascar.**

**Vegetation.** Madagascar was once covered with evergreen and deciduous forest, but these trees are nearly gone due to slash-and-burn farming methods; forests now exist only in remote locations. The tropical rain forests that once covered much of Eastern Madagascar now remain only on the steepest slopes. Comparisons made between 1950 and 1985 showed that about 1,110 square kilometers of rain forest had disappeared. Data from the Landsat satellite in 1990 indicated that only about 10% of the entire island remained forested—mainly the tropical rain forests in the eastern part of the island. Mangrove swamps are prevalent at both ends of the Canal des Pangalanes.

# MAJOR CLIMATIC CONTROLS OF EASTERN MADAGASCAR

**General Climate.** Eastern Madagascar's climate is maritime tropical. The Indian Ocean, the southeast trade winds, and the northeast monsoon are all major factors. The South Indian Ocean (Mascarene) High, the South African High, and the Mozambique Channel low/trough help determine the extent of the influence of the southeast trade winds, the northeast monsoon, and polar outbreaks from the south.

**Southeast Trades.** The positions of the semipermanent features control the strength and position of the southeast trade winds. During the warm season, the South Indian Ocean High is farther south (and weaker) than in the cool season; the southeast trades are therefore stronger in the cool season. Most of the maritime tropical air that reaches Eastern Madagascar has crossed at least 3,000 kilometers of warm-to-hot Indian Ocean waters. The average relative humidity of this air mass is 75% in February, the annual maximum. This air mass becomes unstable over Eastern Madagascar due to topography and thermal effects.

**Northeast Monsoon.** The Northeast Monsoon affects Eastern Madagascar in the warm season mainly from December through March) when the southward shift of the South Indian Ocean High permits the incursion of the monsoon from the north. This air mass, originally dry continental air, is heated adiabatically as it crosses southern Asia. After crossing the equator, the air mass assumes a northwesterly direction. It becomes very moist (relative humidity averages 75 to 80%) while traveling 3,000 kilometers over the Indian Ocean, one of the warmest oceans in the world. It only affects Eastern Madagascar when the near equatorial trough (NET) crosses the island. The NET causes more cloudiness than the Southeast Trades alone.

**Polar Outbreaks.** The positions of the South Indian Ocean High and the South African High control the incursion of polar disturbances into Eastern Madagascar from the south. These Atlantic air masses are rapidly modified as they move along the eastern coast of Madagascar. They assume the characteristics of a cold front, pushing the warmer Indian Ocean air ahead and mixing as they move northward. Relative humidity is 80 to 85% throughout the air mass. Storms are possible year-round, but mostly in the May-October cool season.

## SPECIAL CLIMATIC FEATURES OF EASTERN MADAGASCAR

**Land Sea/Breezes.** Land/sea breezes have a significant effect along the coast, especially in the warm season. The Bay of Antongil is noted for its strong land/sea breezes. The sea breeze is more prominent than the land breeze, which opposes the southeast trade winds. The sea breeze, however, is from the same direction as the trades and its strength is amplified.

**Foehns.** Foehns (warm downslope winds) affect the extreme south of Eastern Madagascar near Tolanaro. As the trade winds flow up the steep eastern slopes along the western border of Eastern Madagascar, some flow is diverted southward, where it descends the slopes near Tolanaro.

**Tropical Cyclones.** Tropical cyclones are a major threat to Eastern Madagascar from December through March, but especially during January and February. Two to three tropical cyclones a year affect the area, but as many as five are possible. These storms develop mostly in the southwest Indian Ocean northeast of the Mascarene Islands between 5° and 10° S. The South Indian Ocean High steers them toward Eastern Madagascar from the northeast. As they approach the island, they usually curve to the southeast. When this happens, they often move away from Eastern Madagascar without touching land. Occasionally, a tropical cyclone develops in the Mozambique Channel and affects Madagascar as it moves east or southeast. These storms are weaker than those that form over the Indian Ocean.

**Low-Level Jet.** In February, a clockwise gyre often develops in the low-level flow over the southern Indian Ocean southeast of the NET. As the NET retreats northward from Madagascar in March and April, this low-level wind band gradually moves northwestward and strengthens, crossing the northern tip of Madagascar. Once it crosses eastern Africa over Somalia (April to May), it is known as the Somali Jet (see Chapter 2). In June and July the jet continues to strengthen. It becomes quasi-stationary through August, when the clockwise gyre moves southeastward. It weakens through October as the northwest monsoon arrives in the area. Wind speeds over Madagascar average 20 to 40 knots.

**General Weather.** Warm season weather in most of Eastern Madagascar is rainy and hot. The southeast trade winds prevail, interrupted by tropical cyclones and the NET. Rare polar disturbances can affect weather in the south. The position and intensity of the South Indian Ocean High control the strength of the southeast trade winds; the high also controls the extent of the incursion of the NET and makes polar disturbances over Madagascar rare. Topography relative to the trade winds also determines the weather here.

Trade winds are a major weather producer even though they are weaker than in the cool season. Their mean direction is nearly perpendicular to the eastern coast and their influence is strongest in the north. The abrupt rise over the cliffs produces copious rainfall. These cliffs also deflect the trades to the north and south. A weakening of the South Indian Ocean High and a shift in mean position to the southeast during the warm season allows the NET to reach Madagascar. From December to March, the NET is either close to or lying across northern Madagascar as a monsoonal trough. As a result, warm-season showers and thunderstorms are more frequent in the northern half. The NET also causes convection well south of the trough line because it slopes southward with height.

Polar lows and their associated frontal systems rarely affect Madagascar's weather during the warm season. They usually stay south of the island and only rarely go north of 25° S. In one 6-year period, only one front affected southern Madagascar during January and February. As lows track farther north early and late in the warm season, fronts are more common.

Tropical cyclones are a major threat, particularly during January and February.

**Sky Cover.** Skies are usually cloudy, with ceilings occurring 60-70% of the time or more in January (Figure 8-2). In November and April, the frequency of ceilings is 10 to 20% lower. During early morning, skies are generally clear to partly cloudy, becoming partly cloudy to cloudy later in the morning as cumulus forms at 2,000 to 3,000 feet. Thunderstorms with bases at 1,500 to 2,000 feet form later in the day. In the vicinity of the NET, broken altocumulus and altostratus extend from 8,000 to 16,000 feet. These clouds can last 2 to 3 days, but they do not prevent the formation of thunderstorms with bases at 1,200 to 1,800 feet. Figure 8-3 shows that the frequency of ceilings below 3,000 feet is lowest at Tolanaro where Foehn-effect winds that descend nearby slopes cause clouds to dissipate. At Antsiranana, most ceilings occur in early afternoon; at other stations, most occur later in the day.

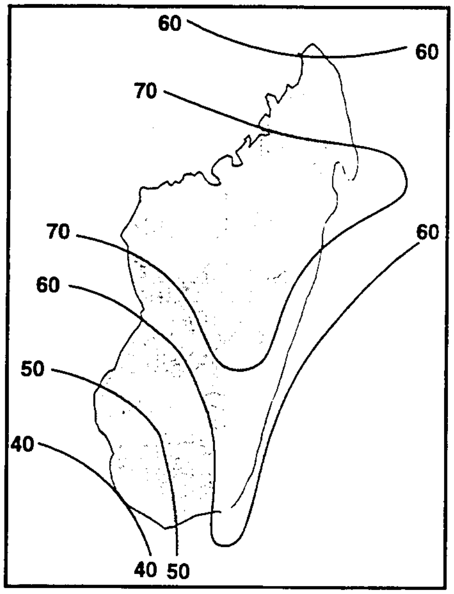



**Figure 8-2. January Percent Frequencies of Ceilings.**

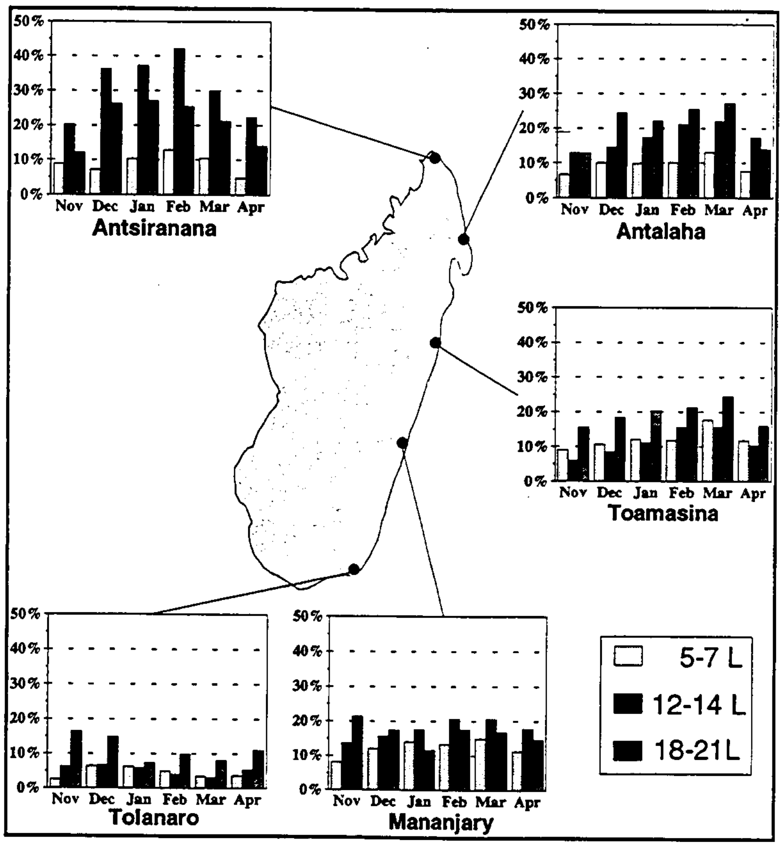



**Figure 8-3. Warm-Season Percent Frequencies of Ceilings Below 3,000 Feet.**

**Visibility.** Visibility is generally good (20-30 kilometers). Fog is rare. Precipitation reduces the visibility to below 4,800 meters less than 10% of the time, but usually less than 5% of the time, as shown in Figure 8-4. Heavy rainfall can reduce visibilities to less than 1 kilometer; torrential rain can lower them to 500 meters or less.

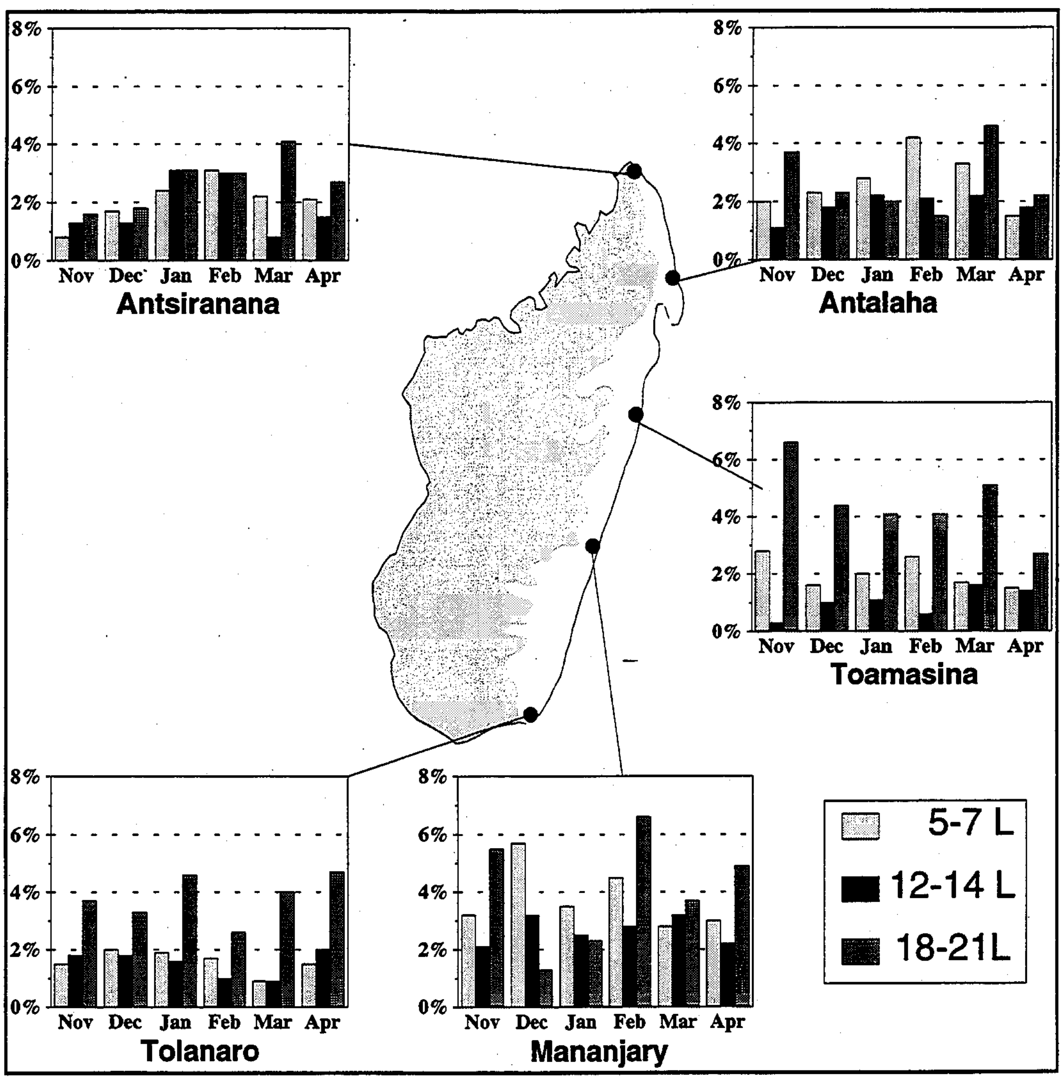



**Figure 8-4. Warm-Season Percent Frequencies of Visibilities Below 4,800 Meters.**

**Surface Winds.** The southeast trade winds are modified by the mountains and the abrupt rise of the central plateau. Figures 8-5 and 8-6 show mean monthly surface winds for January and April. Winds at Antsiranana and Tolanaro are stronger than at other locations because of their exposed locations. The prevailing wind directions reflect the trades; i.e., they are southeasterly at Antsiranana, northeasterly at Tolanaro, and easterly at locations in between.

The land/sea breezes along the east coast are strongest during the warm season, but they don't behave the same everywhere because of terrain differences. The sea breeze is first noticeable at about 0900L and it lasts until about 1800L. The land breeze starts in the evening and lasts until sunrise. Figure 8-7 shows the mean January surface wind roses at selected locations in Eastern Madagascar for 00Z (0300L) and 12Z (1500L). winds are often calm or light and variable during the night, but there is a noticeable land breeze, especially at Antalaha and Mananjary. The diurnal shift of the sea breeze is evident at Antalaha, Toamasina, and Mananjary. Since the sea breeze is from the same general direction as the trade wind, it is enhanced. The winds at Tolanaro show this phenomenon. Although the prevailing wind direction is the same in the morning and afternoon, wind speeds in the afternoon are stronger; speeds are 28 knots or greater about 8% of the time.

At Antsiranana, the prevailing direction in the morning reflects the southeast trades. Sea breezes from both the east and west overpower the trade winds in the afternoon. Antsiranana's location on Madagascar's northern tip, with both east- and west-facing coasts, makes this possible.

Tropical storms can cause sustained winds over 65 knots. Sustained winds can exceed 100 knots, and wind gusts of 100 to 150 knots are possible.

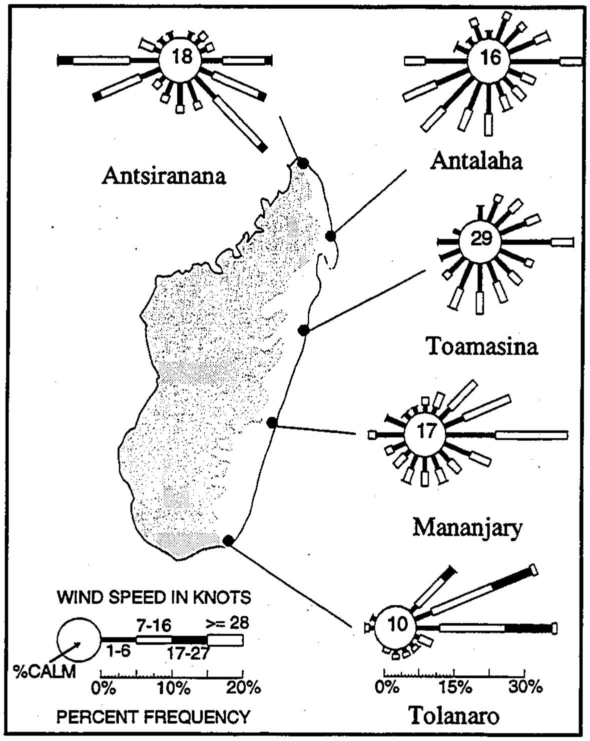



Figure 8-5. January Surface Wind Roses.

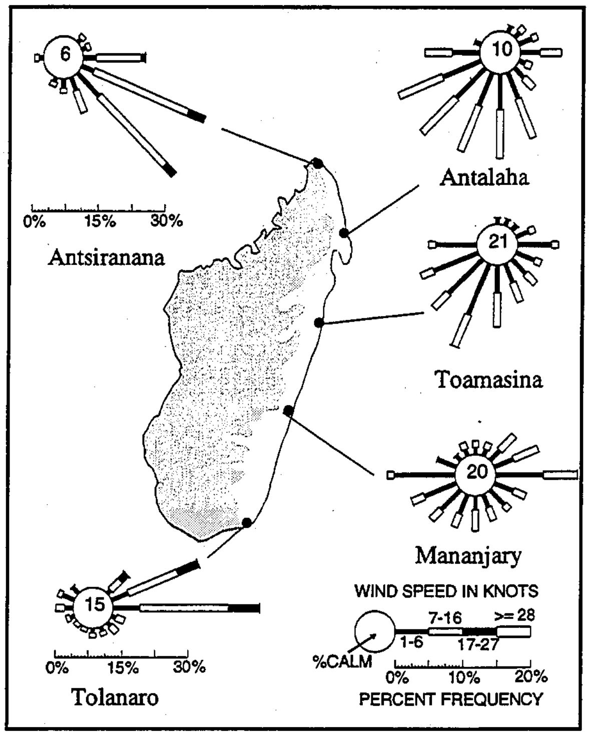



Figure 8-6. April Surface Wind Roses.

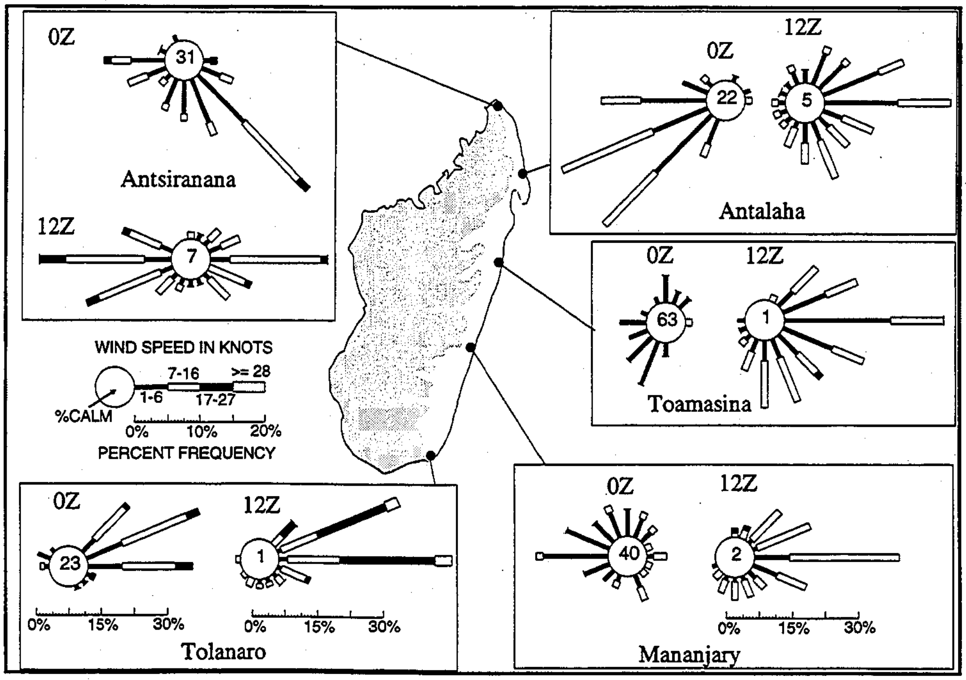



Figure 8-7. 00Z and 12Z Surface Wind Roses for January.

**Winds Aloft.** Strong winds aloft are rare over Eastern Madagascar during the warm season. In the north, southeasterly trade winds persist at lower levels. A low-level jet barely touches the region's extreme north from February to April; the strength of this jet depends on the strength of the South Indian Ocean High. Above 2,000-3,000 meters, wind directions are variable due to the alternating influences of the Northeast Monsoon flow and the southeast trade winds. In the south (see Figure 8-8), northeasterly trade winds are evident at the 850-mb level, but at higher levels, westerlies prevail. In April, as the warm season makes its rapid transition to the cool season, stronger westerly winds prevail; they rarely exceed 75 knots at the 300-mb level.

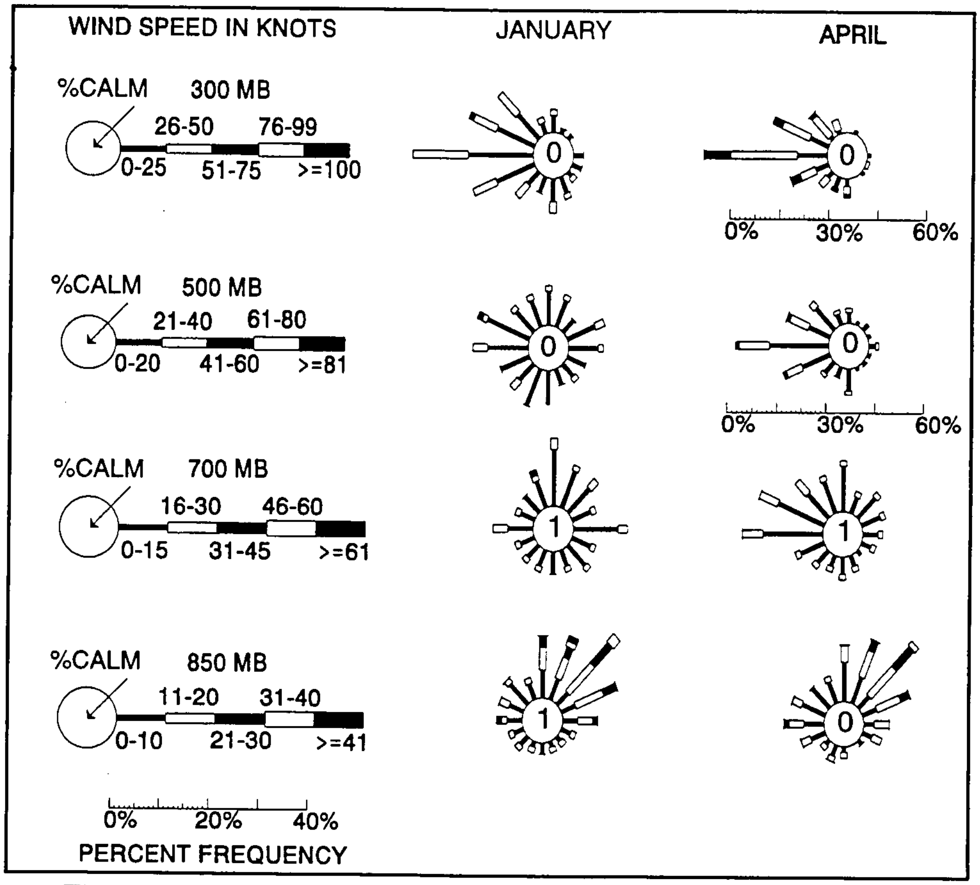



**Figure 8-8. January and April Upper-Air Wind Roses for Tolanaro.**

**Precipitation.** More rain falls in Eastern Madagascar during the warm season than in the cool season. Total warm-season rainfall in Eastern Madagascar ranges from about 1,000 mm to over 2,000 mm as the Northeast Monsoon and the NET in the north cause increased instability. The convergence of the southeast trade winds with the Northeast Monsoon results in more showers and thunderstorms over the northern half to two-thirds of Eastern Madagascar. The southwestern Indian Ocean is relatively hot during this season (26° to 28° C in January—see Figure 2-2), allowing more moisture to evaporate into the southeast trades. Tropical storms also cause more rainfall, particularly from December through March; maximum 24-hour rainfall amounts of more than 500 mm have been recorded with tropical storms.

Exposure to the trade winds also has a significant effect on precipitation. As shown in Figure 8-9, more rain falls from Antalaha southward to Mananjary, where the trade winds are perpendicular to the coast and carry the maximum amount of moisture inland.

January has the most rainfall. In April, rainfall is still high between Antalaha and Mananjary, even though it has decreased somewhat in the rest of Eastern Madagascar. Toamasina has the highest mean number of days per month with rainfall (15-21 days), while most other locations average about 13 days. Antsiranana (the exception) averages 6-16 days (see Figure 8-10, next page).

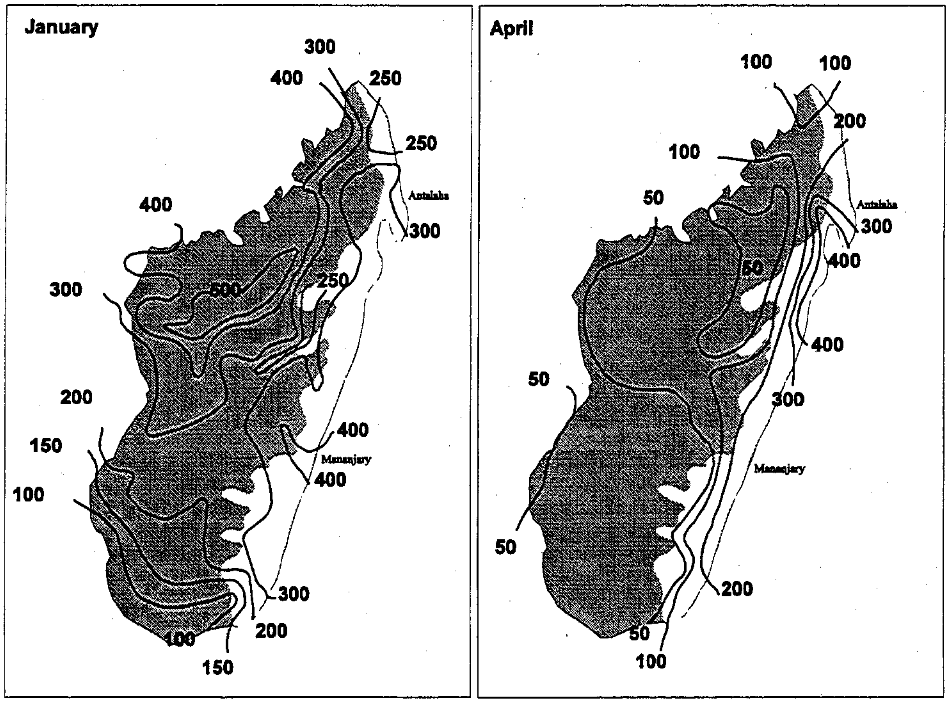



**Figure 8-9. January and April Mean Precipitation (mm).**

**Thunderstorms.** Thunderstorms in Eastern Madagascar are caused mainly by the moist onshore flow along the east coast. Storms are not usually arranged in squall lines. Intense heating and orographic lift enhances the development of thunderstorms, which occur mainly in the late afternoon to evening. Their duration at a given location is usually 20-60 minutes. The convergence of the Northeast Monsoon with the southeast trade winds in the NET results in increased thunderstorm activity over the northern part of the region from December to March, which is the tropical cyclone season. Thunderstorms that accompany tropical cyclones do occur in squall lines; they are severe and tops extend to 40,000 feet. From December to March, thunderstorms occur on about 8-15 days a month in the north; frequency decreases southward to 5 days or less a month—see Figure 8-10. Hail is rare.

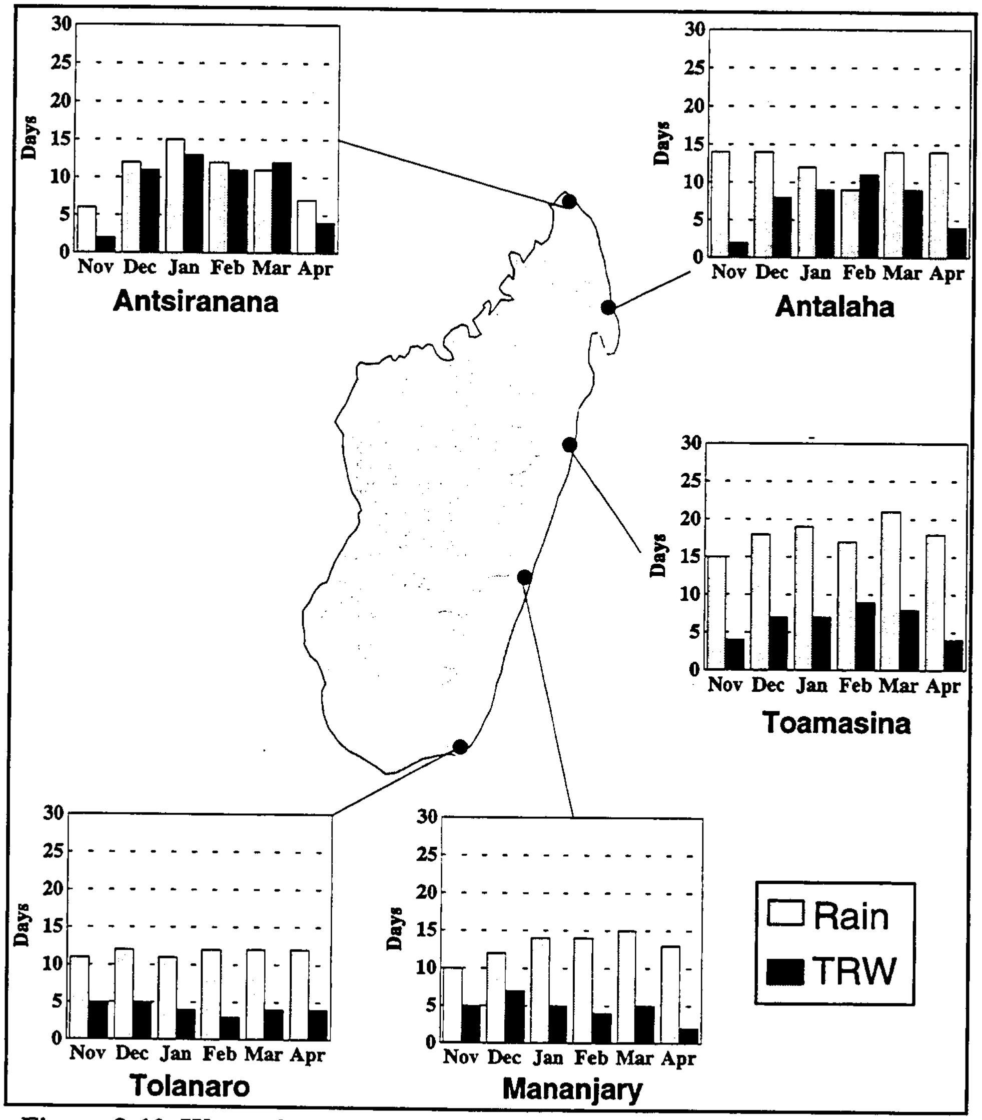



Figure 8-10. Warm-Season Mean Monthly Rain and Thunderstorm Days.

**Temperatures.** January is one of the hottest months of the year; average high temperatures are 28° to 29° C—see Figure 8-11. Temperatures do not vary much throughout the season, but extreme highs of 33° to 38° C are possible. Average January lows of 22° to 24° C are typical of the season. Extreme lows of 15° C are possible, but only late in the season when cold fronts associated with polar lows can reach farther north into Eastern Madagascar.

**Other Hazards.** Tropical storms are accompanied by destructive winds, torrential rains, and floods.

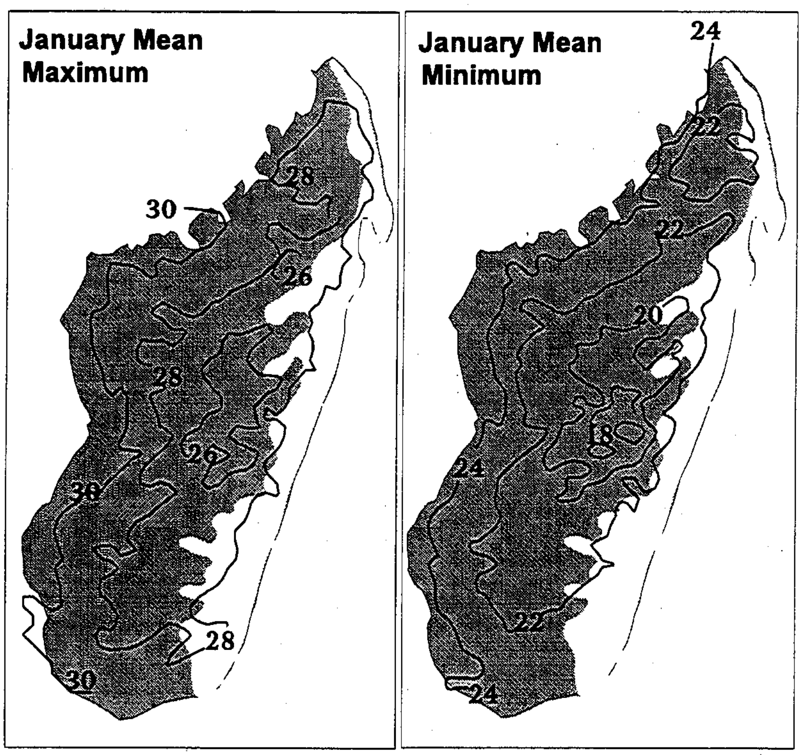



**Figure 8-11. January Mean Maximum and Minimum Temperatures.**

**General Weather.** During the cool season, the South Indian Ocean High strengthens and moves northward, keeping the NET far to the north of Madagascar. The South African High, also strong in the cool season because of the strong radiative cooling of the land mass, extends eastward and joins the South Indian Ocean High.

The southeast trade winds are strongest at this time of year; they dominate Eastern Madagascar's cool-season weather. Tropical cyclones are rare, but a few have affected Eastern Madagascar early in the season. Polar disturbances are the only synoptic-scale features that interrupt the trades. Topography and trade-wind exposure are the primary weather controls.

Trade-wind influence is strongest from the Bay of Antongil to Toamasina. The central plateau diverts the trades so that they are southerly to southeasterly north of the Bay of Antongil and northeasterly south of Toamasina. Abundant rainfall occurs with orographic lift, but less rain falls than in the warm season, partly because of cooler south Indian Ocean water temperatures (22° to 25° C in July).

Lows and their associated frontal systems move toward Madagascar from the southwest. These fronts are often indistinguishable at the surface when they reach Eastern Madagascar. Three or four of these fronts reach as far north as 10° S.

**Sky Cover.** Cloud cover is at its yearly minimum; skies are generally partly cloudy to cloudy. Ceilings are present 40-60% or more of the time in July (Figure 8-12).

The strong southeast trade winds and polar outbreaks cause cumulus and stratocumulus ceilings at 1,000 feet to 2,000 feet along the coast, but low ceilings are uncommon (Figure 8-13).

Low ceilings are least common at Tolanaro, where Foehn-effect winds (the result of deflected southeast trades) descend the surrounding slopes, causing clouds to dissipate.

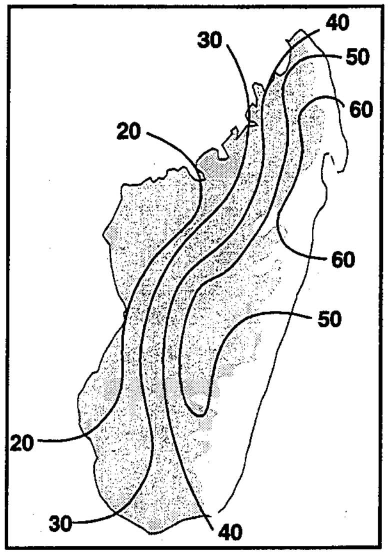



**Figure 8-12. July Percent Frequencies of Ceilings.**

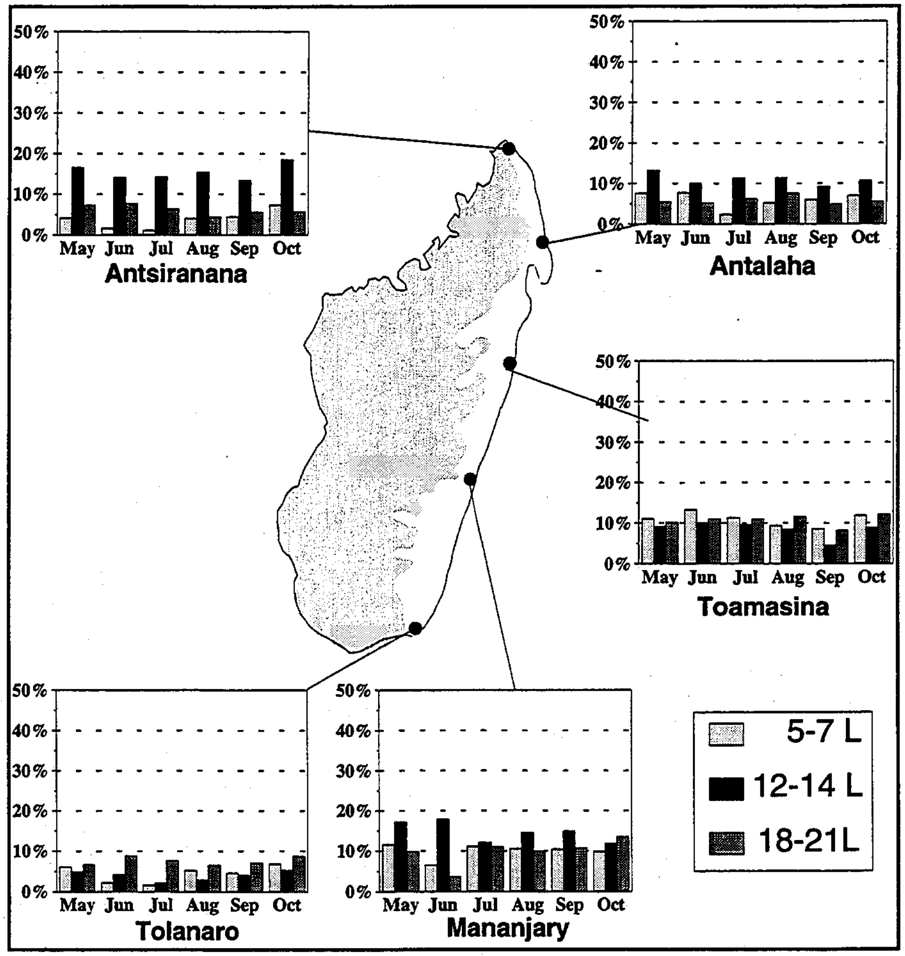



**Figure 8-13. Cool-Season Percent Frequencies of Ceilings Below 3,000 Feet.**

**Visibility** is generally good. Fog is rare. Precipitation reduces visibility to less than 4,800 meters no more than 4% of the time (Figure 8-14). Brief, heavy rainfall can reduce visibility to less than 1 kilometer, and torrential rain can reduce it to 500 meters or less.

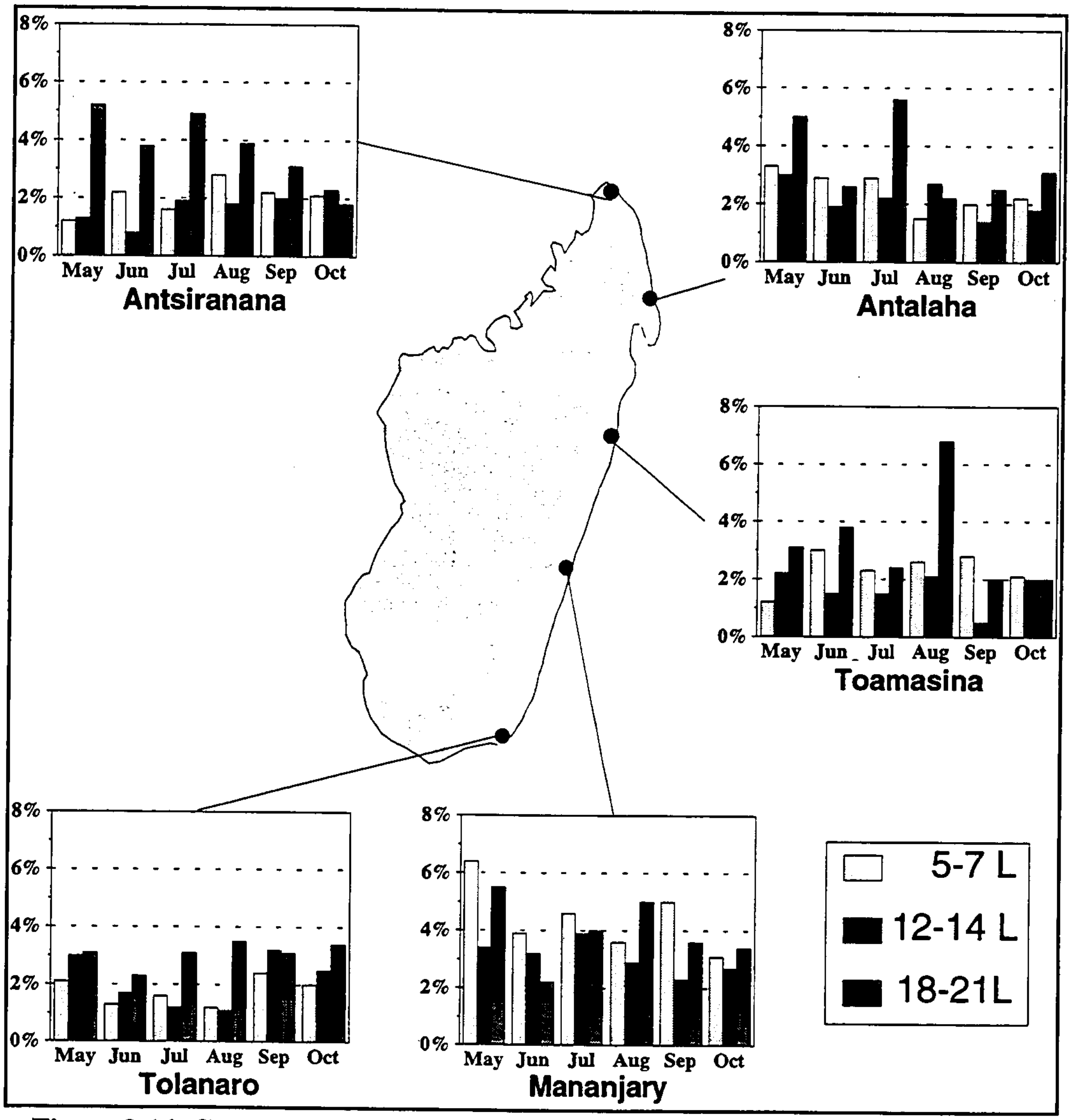



**Figure 8-14. Cool-Season Percent Frequencies of Visibilities Below 4,800 Meters.**

**Surface Winds.** The prevailing southeast trade winds are altered by flow over the mountains and the cliffs of the central plateau. Figures 8-15 and 8-16 show mean monthly surface winds for July and October, respectively. At Antsiranana and Tolanaro, surface winds are stronger than at the other locations due to their exposed locations. Antsiranana's winds are 28 knots or greater about 5% of the time; Tolanaro's, 1-2% of the time.

Prevailing wind directions reflect those of the trade winds; they are southeasterly in the north, northeasterly in the south, and easterly where the trade winds are perpendicular to the coast.

Tropical storms can cause sustained winds over 65 knots; sustained winds can exceed 100 knots, and gusts of 100 to 150 knots are possible.

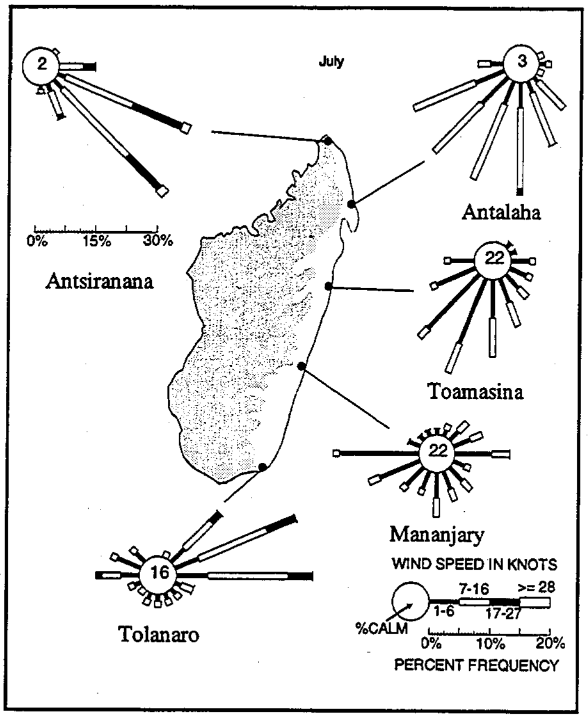



**Figure 8-15. July Surface Wind Roses.**

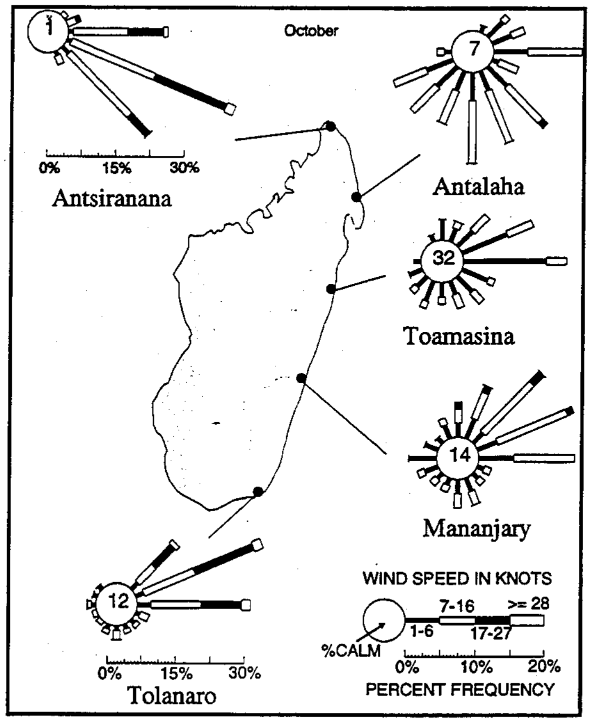



**Figure 8-16. October Surface Wind Roses.**

**Surface Winds, Continued.** The land/sea breezes along the east coast are not as strong as during the warm-season because the heating of the land is not as intense. Generally, the sea breeze is first noticeable at about 0900L; it lasts until about 1800L. The land breeze starts in the evening and lasts for about 10 hours until sunrise. Figure 8-17 shows mean surface wind roses at locations in Eastern Madagascar during July at 00Z (0300L) and 12Z (1500L).

Winds are often calm or light and variable during the night at Toamasina, Mananjary, and Tolanaro. However, a land breeze from the southwest is noticeable at Antalaha and Toamasina. A westerly land breeze shows up at Mananjary. The sea breeze at Antalaha and Toamasina is southerly to southeasterly, but easterly at Mananjary in the afternoon.

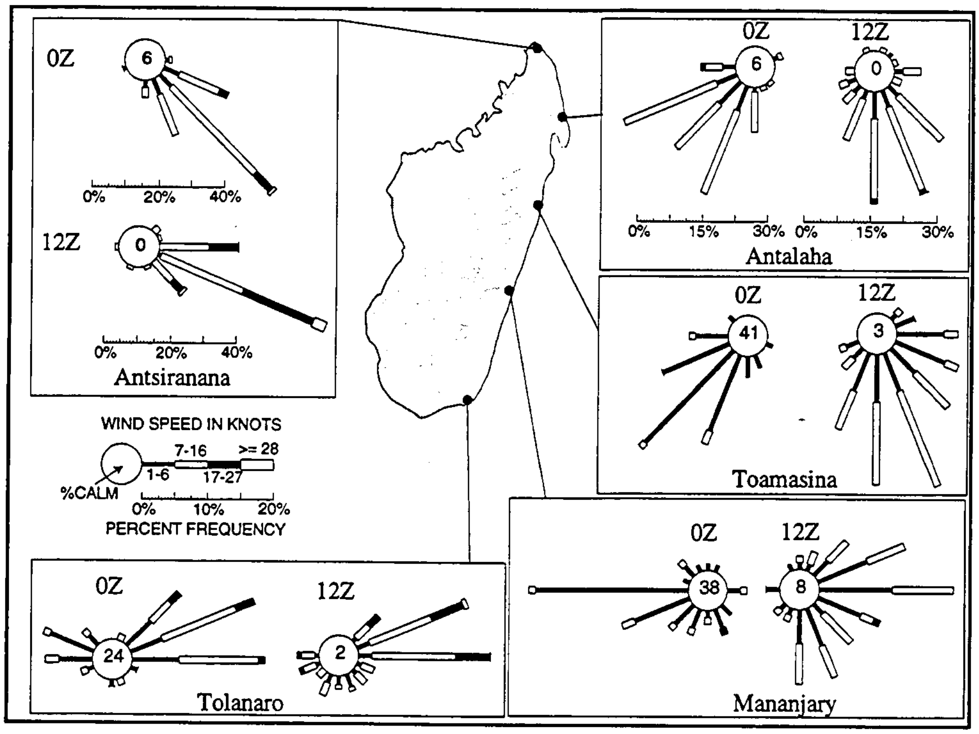



**Figure 8-17. 00Z and 12Z Surface Wind Roses for July.**

**Winds Aloft.** As shown in Figure 8-18, strong winds aloft are rare over Eastern Madagascar during the cool season. In the north, southeasterly trade winds persist at lower levels. The Somali jet crosses the northern tip of Madagascar at about 1,000 meters with average speeds of 20 to 40 knots. Above 2,000-3,000 meters, wind directions are variable until about the 500-mb level, where light westerly winds prevail.

In the south, the trade winds are evident from the northeast at the 850-mb level. At higher levels, westerlies prevail. While the mean position of the southern hemisphere subtropical jet is south of Madagascar, it is occasionally far enough north to cause strong winds at 300 mb. During July, winds are 76-99 knots about 8% of the time and 100 knots or more about 4% of the time.

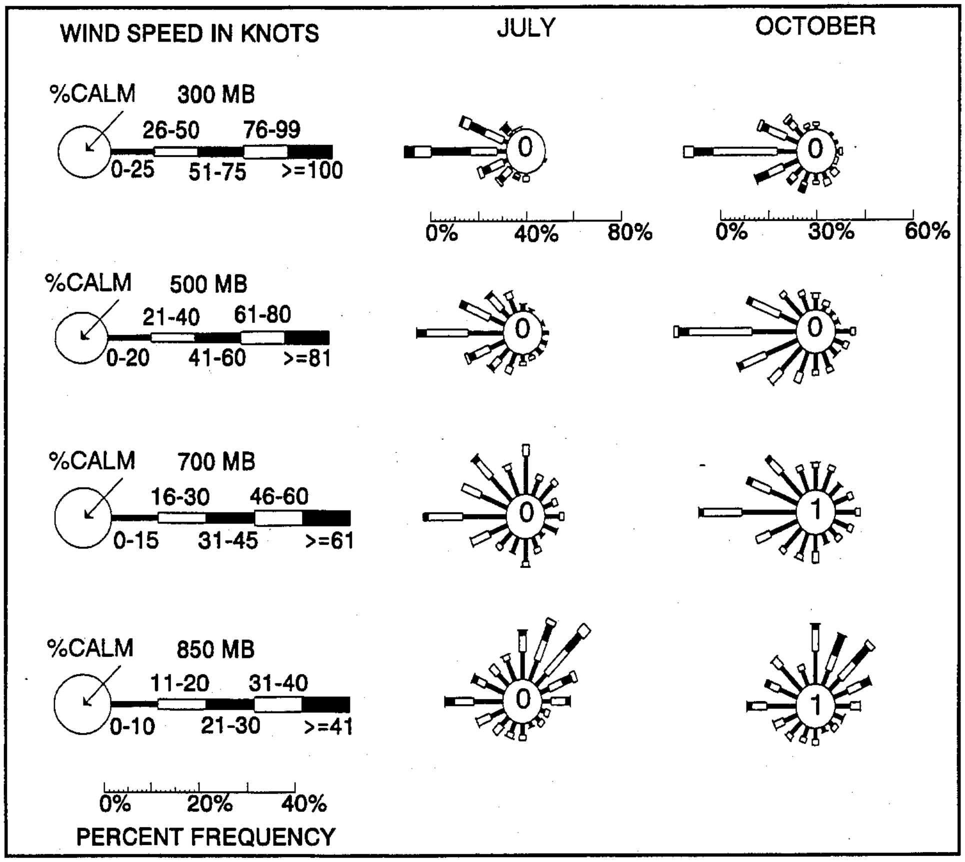



**Figure 8-18. July and October Upper-Air Wind Roses**

**Precipitation.** Total rainfall for the cool season ranges from a minimum of about 50 mm in the extreme north to over 1,200 mm near Toamasina. More rain falls from the Bay of Antongil southward to Toamasina than elsewhere. Figure 8-19 shows mean precipitation amounts during July of 200 mm or more in that area. In the rest of Eastern Madagascar, rainfall in July ranges from a low of about 10 mm at Antsiranana to 200 mm. In October (Figure 8-19), rainfall ranges from about 10 mm in the north to 100 mm or more in the southeast. As shown in Figure 8-20, Toamasina has the highest mean number of days a month with rainfall (16-22 days). Antsiranana has the least rainfall, averaging 5-10 rain days a month.

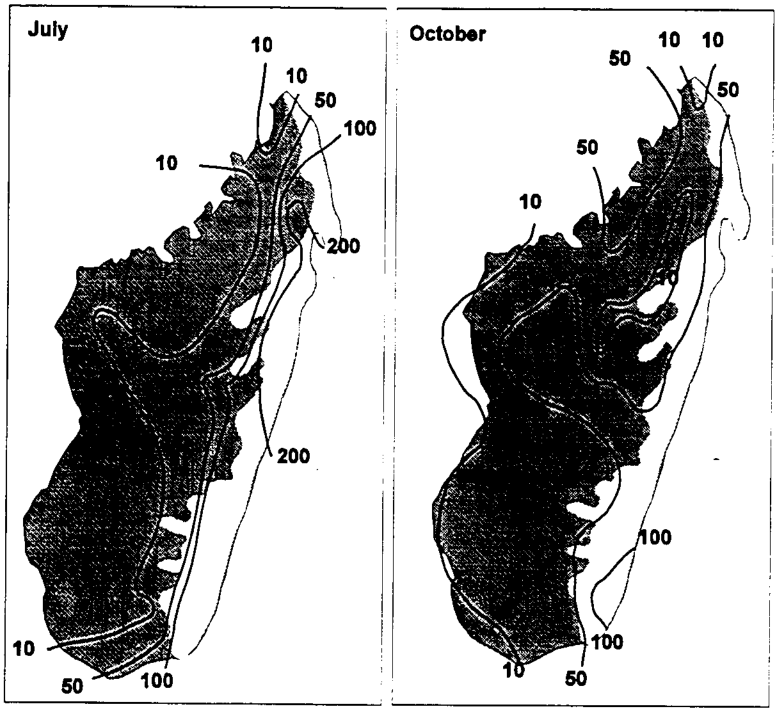



**Figure 8-19. July and October Mean Precipitation (mm).**

**Thunderstorms.** Thunderstorms are rare, occurring only in May, September, and October. Air-mass thunderstorms form mainly in late afternoon and evening. Those associated with tropical cyclones early in the season occur in squall lines, are severe, and extend up to 40,000 feet. Only Antsiranana has thunderstorms on more than 5 days a month (in October— see Figure 8-20). Hail is rare.

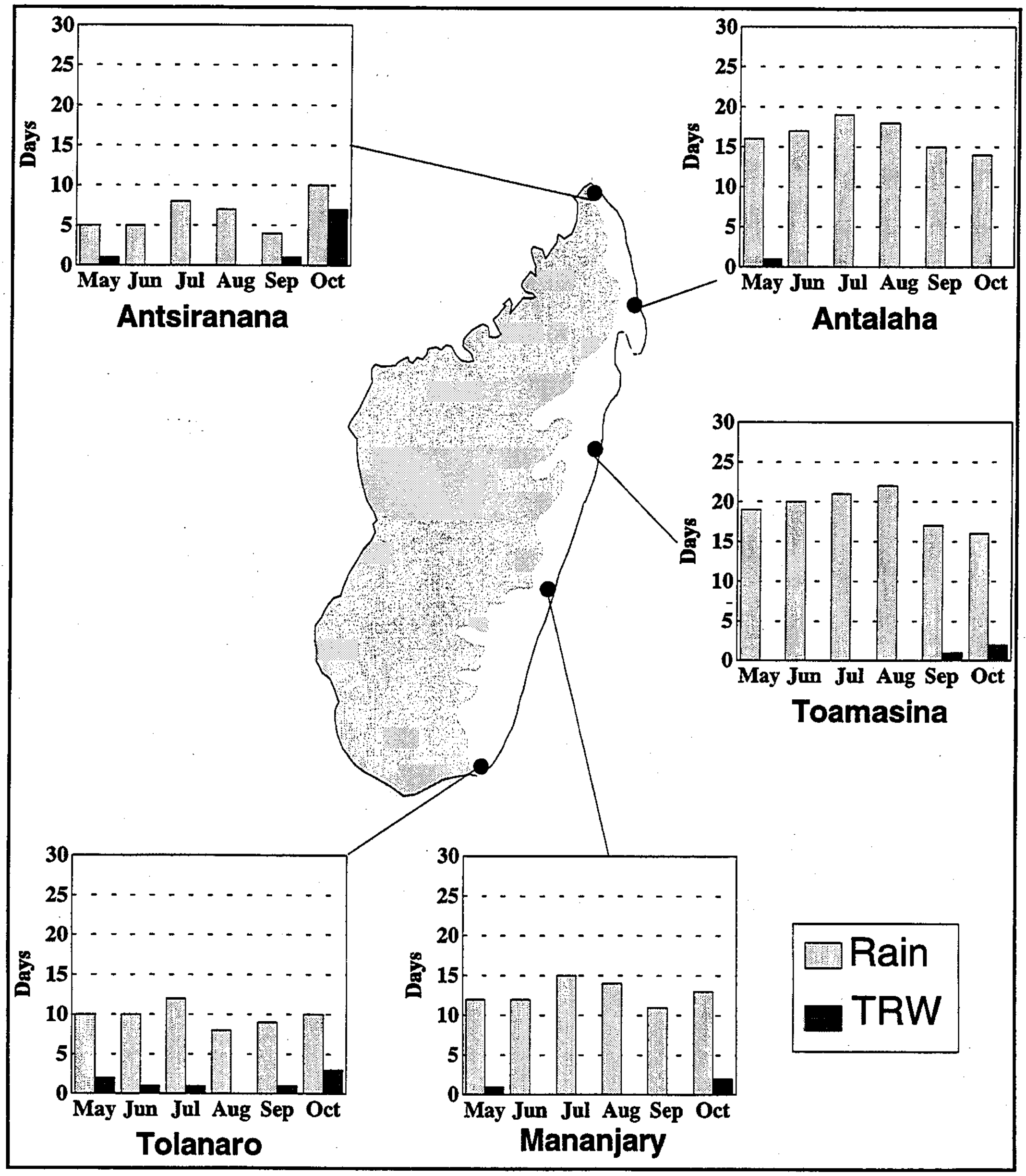



Figure 8-20. Cool-Season Mean Monthly Rain and Thunderstorm Days.

**Temperatures.** July is the coolest month of the year. Temperatures are higher during the transitions between the cool and warm seasons. Average high temperatures in July range from 22° C in the southern part of Eastern Madagascar to 28° C in the north (see Figure 8-21).

Extreme highs range from 37° C in the north to 32° C in the south during May and October, the two warmest months. Average lows in July are 16° to 20° C . Extreme lows of 10° C are possible in the south during June and July, generally due to unusually strong polar lows.

**Other Hazards.** Tropical cyclones, although rare in the cool season, can cause destructive winds, torrential rains, and flooding.

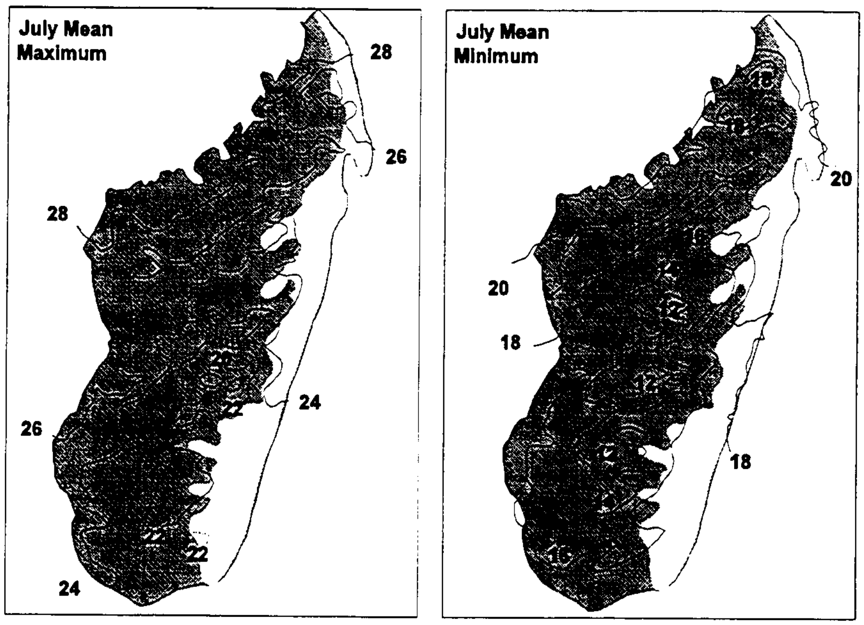



**Figure 8-21. July Mean Maximum and Minimum Temperatures.**

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90 OSS DOW, 7505 SABER RD BLDG 1250 RM 154, F E WARREN AFB WY 82005-2684 .......... 1
341 OSS DOW, 7224 FLIGHTLINE DR ROOM 209, MALMSTROM AFB MT 59402-7526 .......... 1
ADF WE STOP 77, 18201 E DEVILS THUMB AVE, AURORA CO 80011-9536 .......... 1
CAPE CANAVERAL FCST FACILITY/ROCC, BLDG 81900, CAPE CANAVERAL AFS FL 32925-6537 .......... 1
AFSFC SYT, 715 KEPLER AVE STE 60, FALCON AFB CO 80918-7160 .......... 1
HQ AFSPACECOM/DOGW, 150 VANDENBERG ST STE 1105, PETERSON AFB CO 80914-4200 .......... 1

15 AF DOW, MARCH AFB CA 92518-5000 .......... 1
22 OSS OSW, 53435 KANSAS CT STE 110, MCCONNELL AFB KS 67221-3720 .......... 1
60 OSS/OSW, 401 SECOND STREET, TRAVIS AFB CA 94535-5030 .......... 1
62 OSS/OSW, 1172 E STREET RM 127, MCCHORD AFB WA 98438-1008 .......... 1
89 OSS/OSW, 1240 MENOHER DR BLDG 1220, ANDREWS AFB MD 20331-6511 .......... 1
92 OSS/OSW, 901 WEST BONG STE 101, FAIRCHILD AFB WA 99011-8529 .......... 1
305 OSS/OSW, 1730 VANDENBERG AVENUE, MCGUIRE AFB NJ 08641-5509 .......... 1
375 OSS/OSW, 433 HANGAR RD, SCOTT AFB IL 62225-5029 .......... 1
377 ABW OTW, 3400 CLARK AVE SE, KIRTLAND AFB NM 87117-5776 .......... 1
380 OSS/OSW, 22 ALABAMA AVE STE 207, PLATTSBURGH AFB NY 12903-2705 .......... 1
434 OSS/ATWX, BLDG S 28 HOOSIER BLVD, GRISSOM AFB IN 46971-5000 .......... 1
436 OSS/OSW, 501 EAGLE WAY ST, DOVER AFB DE 19902-7504 .......... 1

437 OSS/OSW, 101 S BATES ST STE A, CHARLESTON AFB SC 29404-5013 .................................. 1
722 OSS/OSW, 2645 GRAEBER ST STE 3, MARCH AFB CA 92518-2331 .................................. 1
AMC/DOW, 402 SCOTT DR UNIT 3A1, SCOTT AFB IL 62225-5302 .................................. 1
AMC/DOWR, 402 SCOTT DR UNIT 3A1, SCOTT AFB IL 62225-5302 .................................. 1
TACC/WXC, 402 SCOTT DRIVE RM 132, SCOTT AFB IL 62225-5029 .................................. 1

12 OSS DOW, H 08, 1350 5TH ST EAST, RANDOLPH AFB TX 78150-4410 .................................. 1
14 OSS DOW, 595 1ST ST STE # 3, COLUMBUS AFB MS 39710-4201 .................................. 1
42 OS, 40 ARNOLD ST S, MAXWELL AFB AL 36112-6601 .................................. 1
47 OSS DOW, 541 1ST ST STE 2, LAUGHLIN AFB TX 78843-5210 .................................. 1
58 OSS OSW, 7254 N 142 AVE STE 3, LUKE AFB AZ 85309-1233 .................................. 1
OL A 58 OSS OSW, BLDG 324, GILA BEND AFAF AZ 85337-5000 .................................. 1
64 OSS DOW, 145 N DAVIS DR, REESE AFB TX 79489-5000 .................................. 1
71 OSS DOW, 623 ELAM RD STE 110, VANCE AFB OK 73705-5412 .................................. 1
80 OSS/DOAW, 620 J AVENUE STE 3, SHEPPARD AFB TX 76311-2553 .................................. 1
81 SPTG OSFWX, 817 H ST STE 102, KEESLER AFB MS 39534-2452 .................................. 1
97 OSS WXF, 603 E AVE STE 1, ALTUS AFB OK 73523-5033 .................................. 1
325 OSS OSW, STOP 22 408 FLIGHTINE RD2, TYNDALL AFB FL 32403-5124 .................................. 1
334 TRS TTMV, 700 H ST BLDG 4332, KEESLER AFB MS 39534-2499 .................................. 1
AETC/XOSW, 1F ST STE 2, RANDOLPH AFB TX 78150-4325 .................................. 1
AFIT CIR, WRIGHT-PATTERSON AFB OH 45433-6583 .................................. 1
AFIT LDEE, 2950 P ST BLDG 640, WRIGHT-PATTERSON AFB OH 45433-7765 .................................. 1
AUL/LSE, BLDG 1405 600 CHENNAULT CIRCLE, MAXWELL AFB AL 36112-6424 .................................. 1

AFGWC DO, 106 PEACEKEEPER DR STE 2N3 MBB 39, OFFUTT AFB NE 68113-4039 .................................. 1
AFGWC DOM, 106 PEACEKEEPER DR STE 2 N3 MBB 39, OFFUTT AFB NE 68113-4039 .................................. 1

AWS XO, 102 WEST LOSEY ST RM 211, SCOTT AFB IL 62225-5206 .................................. 1
AWS XOOM, 102 WEST LOSEY ST, RM 214, SCOTT AFB IL 62225-5206 .................................. 1
AWS XOT, 102 WEST LOSEY STRM 218 SCOTT AFB IL 62225-5206 .................................. 1
DET 4 AWS, 595 INDEPENDENCE RD BLDG 91027, HURLBURT FLD FL 32544-5618 .................................. 1
DET 5 AWS, WALL STUDIO 709 H ST STE 201 BLDG 0902, KEESLER AFB MS 39534-2447 .................................. 1
OL-F HQ AWS (SMC/CIA), 2420 VELA WAY SUITE 1467 A 8, LOS ANGELES AFB CA 90245-4659 .................................. 1
OL N AWS, C/O ARL (AMSRL-BE-W) BLDG 1646 RM 24, WHITE SANDS MSSL RNGE NM 88002-5501 .................................. 1
AWSTL, FL4415 859 BUCHANAN ST, SCOTT AFB IL 62225-5118 .................................. 125
OL A USAFETAC, FEDERAL BLDG RM 305 PAGE AVE, ASHEVILLE NC 28801-2723 .................................. 1

DEFENSE INTELLIGENCE AGENCY, DIA D1W 1B DIAC RM A4-130, WASHINGTON DC 20340-6612 .................................. 1
DTIC-FDAC, CAMERON STATION, ALEXANDRIA VA 22304-6145 .................................. 1
FEDERAL COORD MET OFMC, 8455 COLESVILLE ROAD STE 1500, SILVER SPRING MD 20910-5000 .................................. 1
NATO LMS/OPS, STAFF METEOROLOGICAL OFFICER, APO AE 09724 .................................. 1
NGB XOOSW, MAIL STOP 18, ANDREWS AFB MD 20331-6008 .................................. 1
NORAD/US/J2D, 1 NORAD RD STE 101-130 (SWO), CHEYENNE MTN CO 80914-6092 .................................. 1
US ATLANTIC COMMAND, 1562 MITSCHER AVENUE STE 200, NORFOLK VA 23551-2488 .................................. 1
USAFALCENT RA, POPE AFB NC 28308-5000 .................................. 1
USCENTCOM CCJ3-W, BLDG 540, MACDILL AFB FL 33608-7001 .................................. 1
USCINCPAC (J37), BOX 13, CAMP H.M. SMITH HI 96861-5025 .................................. 1
USEUCOM J3 OD WE, UNIT 30400 BOX 1000, APO AE 09128-4209 .................................. 1
USSOCCENT SCJ2- SWO, 7115 S BOUNDARY DRIVE, MACDILL AFB FL 33621-5101 .................................. 1
USSOCOM SOJ3 OW, 7701 TAMPA POINT BLVD, MACDILL AFB FL 33621-5323 .................................. 1
USSOUTHCOM SWO, UNIT 0640, APO AA 34001-5000 .................................. 1
USSPACECOM J3W, 250 S PETERSON BLVD STE 317, PETERSON AFB CO 80914-3230 .................................. 1
USSTRATCOM J 315, 901 SAC BLVD STE 1B29, OFFUTT AFB NE 68113-6300 .................................. 1
USSTRATCOM/J3615, 901 SAC BLVD STE 1F14, OFFUTT AFB NE 68113-6700 .................................. 1
USTRANSCCOM J3/4 OW, 508 SCOTT DR BLDG 1900, SCOTT AFB IL 62225-5357 .................................. 1

NCDC LIBRARY, FEDERAL BUILDING, ASHEVILLE NC 28801-2733 .......... 1
NIST PUBS PRODUCTION, RM A635 ADMIN BLDG, GAITHERSBURG MD 20899 .......... 1
NOAA NWS W/OM21, SSMC-2 ROOM 13148 1325 E-W HIGHWAY, SILVER SPRING MD 20910-3283 .......... 1
NOAA LIBRARY-EOC4W5C4, ATTN: ACQ 6009 EXECUTIVE BLVD, ROCKVILLE MD 20852 .......... 1
NOAA CENTRAL LIBRARY, 1315 EAST-WEST HIGHWAY STE 2000, SILVER SPRING MD 20910 .......... 1
NOAA/MASC LIBRARY MC5, 325 BROADWAY, BOULDER CO 80303-3328 .......... 1

3 OSS WE, 7TH ST BLDG 32235, ELMENDORF AFB AK 99506-3097 .......... 1
5TH WEATHER SQUADRON, UNIT 15173 BLDG 1506, APO AP 96205-0108 .......... 1
DET 1 5 WS, UNIT 15678, APO AP 96205-0678 .......... 1
OL A DET 1 5 WS, UNIT 15630 BLDG 1610, APO AP 96208-0195 .......... 1
OL B DET 1 5 WS, BLDG S 252 UNIT 15242, APO AP 96250-0420 .......... 1
OL C DET 1 5 WS, BLDG S 3101 RM 4, APO AP 96297-0626 .......... 1
DET 2 5 WS, UNIT 15200 BLDG S 819, APO AP 96271-0136 .......... 1
OL A DET 2 5 WS, UNIT 15673, APO AP 96218-0673 .......... 1
OL B DET 2 5 WS, UNIT 15037 BLDG T2651, APO AP 96224-0216 .......... 1
DET 3 5 WS, UNIT 15674, APO AP 96258-0674 .......... 1
OL A DET 3 5 WS, UNIT 15675, APO AP 96257-0675 .......... 1
OL B DET 3 5 WS, UNIT 15118, APO AP 06224-0421 .......... 1
OL C DET 3 5 WS, APO AP 96257-0677 .......... 1
8 OSS WX, UNIT 2139 BLDG 2858, APO AP 96264-2139 .......... 1
11 OG WF, 6900 9TH ST STE 205, ELMENDORF AFB AK 99506-2250 .......... 1
15 OSS/OSW, 800 HANGAR AVE, HICKAM AFB HI 96853-5244 .......... 1
18 OSS/OSW, UNIT 5177 BOX 40, APO AP 96368-5177 .......... 1
343 WS, 1215 FLIGHTLINE AVE STE 2, EIELSON AFB AK 99702-1502 .......... 1
374 OSS DOW, UNIT 5222, APO AP 96328-5222 .......... 1
OL A 374 OSS, APO AP 96343-0085 .......... 1
432 OSS OSW, UNIT 5011, APO AP 96319-5011 .......... 1
603 ACCS/WE, UNIT 2051, APO AP 96278-2072 .......... 1
633 OSS/OSW, UNIT 14035 BOX 54, APO AP 96543-4035 .......... 1
DET 1 633 OSS, PSC 489 BOX 20, FPO AP 96536-0051 .......... 1
643 SPTS OFW, UNIT 12526, APO AP 96513-2526 .......... 1
673 OPS WE, UNIT 12509, APO AP 96512-2509 .......... 1
PACAF DOW, 25 E ST STE I232, HICKAM AFB HI 96853-5426 .......... 1

1CC AZSB-GTFD, AH-64 CSM ATTACK, FT CAMPBELL AI KY 42223-5000 .......... 1
ARMED FORCES MED INTEL CTR, INFO SV DV BLD 1607 FT DETRICK, FREDERICK MD 21702-5004 .......... 1
ARMY TRAINING AND DOCTRINE COMMAND, ATDO-IW (ATTN: SWO), FT MONROE VA 23651-5000 .......... 1
CDR USASOC, ATTN: AOIN-ST, FT BRAGG NC 28307-5200 .......... 1
COMMANDER, FORCES COMMAND, AFIN-ICW, FT MCPHERSON GA 30330-6000 .......... 1
DA DCS OPS PLANS, DAMO-ZD RM 3A538, 400 ARMY PENTAGON, WASHINGTON DC 78234-7001 .......... 1
DIRECTOR USA-CETEC, ATTN: GL-AE, FT BELVOIR VA 22060-5546 .......... 1
DUGWAY PROVING GROUND, TROP TST SITE UNIT 7140, STEDP-MT-TM-TP, APO AA 34004-5000 .......... 1
HQ 5TH U.S. ARMY, AFKB-OP (SWO), FT SAM HOUSTON TX 78234-7001 .......... 1
HQ 629TH MI BN (CEWI), 29TH ID (LIGHT), 7100 GREENBELT ROAD, GREENBELT MD 20770-3398 .......... 1
HQ ARCENT, AFRD-DSO-SWO, FT MCPHERSON GA 30330-7000 .......... 1
NAT RNGE DIR, MET BR ATTN: STEWS-NR-DA-F, WHITE SANDS MISSILE RANGE NM 88002-5504 .......... 1
TECHNICAL LIBRARY, DUGWAY PROVING GROUND, DUGWAY UT 84022-5000 .......... 1
TEXCOM FSTD, ATTN: CSTE-TFS-SP, FT SILL OK 73503-6100 .......... 1
USA INTEL CTR (WEATHER SUPPORT TEAM), ATTN ATZS CDI-W, FT HUACHUCA AI AZ 85613-6000 .......... 1
USA TECOM, ATTN: AMSEL-TC-AM(BE) C O NVESD, FT BELVOIR VA 22060-5677 .......... 1
USA TECOM, ATTN: AMSEL-RD-NV-VMD (MET), FT BELVOIR VA 22060-5677 .......... 1
USA ARMY ENGINEER TOPOGRAPHIC LAB, ATTN: CEETL-TD, FT BELVOIR VA 22310-3864 .......... 1
USA CBT SYS TST ACY, MET BR, BLD 1134, ABERDEEN PROVING GROUND MD 21005-5059 .......... 1
USA REDSTONE TECH TEST CENTER, ATTN: STERT-TE-F-MT, REDSTONE ARSENAL AL 35898-8052 .......... 1
USA RES LAB, BATTLEFIELD ENV DIR AMSRL-BE, WHITE SANDS MISSILE RANGE NM 88002-5501 .......... 1

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|---|---|
| 3 AF/DOW, UNIT 4840, APO AE 09459-4840 | 1 |
| 10 OSS OSW, UNIT 5605 BOX 175, APO AE 09470-5175 | 1 |
| 16 AF WE, UNIT 6365, APO AE 09601-6365 | 1 |
| 17 AF/WE, UNIT 4065, APO AE 09136-5000 | 1 |
| 31 OSS OSW, UNIT 6170 BLDG 904, APO AE 09601-6170 | 1 |
| 39 OSS OSW, UNIT 1075 BOX 275, APO AE 09824-0275 | 1 |
| 48 OSS DOM, UNIT 5245 BOX 390, APO AE 09464-5390 | 1 |
| 52 OSS WEF, UNIT 8870 BOX 270, APO AE 09126-0270 | 1 |
| 86 OSS/DOW, UNIT 8495, APO AE 09094-8495 | 1 |
| 86 OSS/OSW, UNIT 470, APO AE 09136-4070 | 1 |
| 100 OSS DOW, UNIT 4965 BLDG 500, APO AE 09459-4965 | 1 |
| 435 OSS DOW, UNIT 9080 BOX 190, APO AE 09097-0190 | 1 |
| 617 WS, UNIT 29351 BLDG 12, APO AE 09014-5000 | 1 |
| A FLT 617 WS, UNIT 29231, APO AE 09102-3737 | 1 |
| DET 7 617 WS, UNIT 28130, APO AE 09114-5000 | 1 |
| DET 6 617 WS, UNIT 29632, APO AE 09096-5000 | 1 |
| DET 8 617 WS, UNIT 25202 HQ V CORPS G2 SWO, APO AE 09079-5000 | 1 |
| DET 1 617 WS, UNIT 30400 BOX 1000, APO AE 09128 | 1 |
| DET 3 617 WS, CMR 416 BOX S, APO AE 09140-9998 | 1 |
| DET 9 617 WS, UNIT 28216, APO AE 09173-5000 | 1 |
| DET 10 617 WS, UNIT 26410 BLDG 543 RM 111, APO AE 09182-0006 | 1 |
| DET 2 617 WS, UNIT 20200 BLDG 1310, APO AE 09165-9816 | 1 |
| DET 4 617 WS, UNIT 7890 EUROPEAN FORECAST CENTER, APO AE 09126-7890 | 1 |
| DET 5 617 WS, CMR 454 UNIT 31020, APO AE 09250-0047 | 1 |
| OL D 617 WS, C/O CMR 431, APO AE 09175-6321 | 1 |
| OL A 617 WS, C/O 527 MI OPS, APO AE 09157-5000 | 1 |
| OL A DET 8 617 WS, UNIT 29719 BOX 363, APO AE 09028-3728 | 1 |
| OL A DET 2 617 WS, CMR 438 UNIT 5240 WEATHER OFFICE, APO AE 09111-5000 | 1 |
| OL E 617 WS, UNIT 31401 BOX 6, APO AE 09630-0006 | 1 |
| OL C 617 WS, CMR 445 BOX 260, APO AE 09046-5000 | 1 |
| OL B 617 WS, CMR 423, APO AE 09107-5000 | 1 |
| USAFE XOOW, UNIT 3050 BOX 15 BLDG 546 ROOM 306, APO AE 09094-5015 | 3 |
| CO NAVAL POLAR OCEAN CTR, 4301 SUITLAND ROAD FOB #4, WASHINGTON DC 20395-5108 | 1 |
| CO NAVAL OCEANOGRAPHY COMMAND CTR, PSC 819 BOX 13, FPO AE 09645-3200 | 1 |
| COMMANDING OFFICE NEMOC, PSC 819 BOX 31, FPO AE 09645-3200 | 1 |
| COMNAVOCEANCOM, CODE N332, STENNIS SPACE CTR MS 39529-5001 | 1 |
| COMNAVOCEANCOM, CODE N312, STENNIS SPACE CTR MS 39529-5000 | 1 |
| FNOC LIBRARIAN, FLENUMOCEANEN, MONTEREY CA 93943-5005 | 1 |
| MAURY OCEAN LIB, NOO N4312, BLDG 1003, STENNIS SPACE CTR MS 39522-5001 | 1 |
| NAVAL RESEARCH LABORATORY, CODE 4323, WASHINGTON DC 20375 | 1 |
| NAVAL RESEARCH LABORATORY, CODE 4180, WASHINGTON DC 20375 | 1 |
| NAVAL WESTERN OCEAN CTR, ATTN: TECH LIBRARY BOX 113, PEARL HARBOR HI 96860-7000 | 1 |
| NAVAL POSTGRADUATE SCHOOL, CHMN DEPT OF MET CODE 63, MONTEREY CA 93943-5000 | 1 |
| NAVAL EASTERN OCEANOGRAPHY CTR, U117 MCCADY BLDG, NORFOLK NAS VA 23511-5000 | 1 |
| NAVAL RESEARCH LABORATORY, MONTEREY CA 93943-5006 | 1 |
| NAVOCEANCOMDET, FEDERAL BUILDING, ASHEVILLE NC 28801-2696 | 1 |
| NAVOCEANCOMDET, PATUXENT RIVER NAS MD 20670-5103 | 1 |
| NAVOCEANCOMFAC, NAS NORTH ISLAND, SAN DIEGO CA 92135-5130 | 1 |
| NAVOCEANO, CODE 9220, STENNIS SPACE CTR MS 39529-5001 | 1 |
| NAVOCEANO, CODE N25131 BLDG 8100 RM 203D, STENNIS SPACE CTR MS 39522-5001 | 25 |
| NAVOCEANO, CODE N2513 1002 BALCH BLVD, STENNIS SPACE CTR MS 39522-5001 | 1 |
| NAWC-WEAPONS DIVISION, GEOPHYSICAL SCI BRANCH CODE 3254, POINT MUGU CA 93042-5001 | 1 |
| WSO, H & HS MARINE STATION WEA, MCAS TUSTIN CA 92710-5000 | 1 |